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INFRASOUND AND THE INFRASONIC MONITORING OF ATMOSPHERIC NUCLEAR EXPLOSIONS:

An Annotated Bibliography

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13. ABSTRACT (Maximum 200 words)

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The review covers papers published during the time period extending from 1874 to 1996 and is based on literature searches conducted at the NTIS (National Technical Information Service), DTIC (Defense Technical Information Center), DSWA (Defense Special Weapons Agency), AFTAC (Air Force Tactical Applications Center) and from various refereed open literature journals.

The report also reproduces the "Bibliography of Infrasonic Waves," which was published in the 1971 Volume 26 special issue on infrasonics and atmospheric acoustics published by The Geophysical Journal of the Royal Astronomical Society and a list of references provided in *Gossard and Hooke's* 1975 book: WAVES IN THE ATMOSPHERE: Atmospheric Infrasound and Gravity Waves - their Generation and Propagation.

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In addition to providing the annotated bibliography, the report reproduces the **"Bibliography of Infrasonic Waves,"** which was published in the 1971 Volume 26 special issue on infrasonics and atmospheric acoustics published by The Geophysical Journal of the Royal Astronomical Society and a list of references provided in *Gossard and Hooke's* 1975 book: **WAVES IN THE ATMOSPHERE: Atmospheric Infrasound and Gravity Waves - their Generation and Propagation.**

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The author would like to express his sincere appreciation to Dr. Robert Blandford of AFTAC for suggesting this work and to Ms. Leslie Casey of the DOE for her support and encouragement during its conduct. Special appreciation is due Dr. Rodney Whitaker of the Los Alamos National Laboratory for both his support and for making available several of the references cited herein.

1.0 INTRODUCTION

This report presents an annotated and unclassified bibliography of selected references from refereed and other literature sources which are deemed relevant to those governmental, industry and academic institutions interested in the technical aspects of infrasound, in general, and in the particular use of infrasound to monitor compliance within the context of a comprehensive nuclear test ban treaty (CTBT). The report is one of four resulting from a DOE (Department of Energy) supported one-year investigation and review of past work in infrasound.

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- American Scientist
- Applied Acoustics
- British Journal of Applied Physics
- Bulletin of the American Meteorological Society
- Canadian Journal of Physics
- Geophysical Journal of the Royal Astronomical Society
- Geofisica Pura E Applicata
- IEEE Transactions on Geoscience Electronics
- IEEE Transactions on Nuclear Science
- Izvestiya, Atmospheric and Oceanic Physics
- Journal of Atmospheric Science
- Journal of Atmospheric and Terrestrial Physics
- Journal of Applied Meteorology
- Journal of Computational Physics
- Journal of Geophysical Research Space Physics
- Journal of Meteorological Research
- Journal of Research National Bureau of Standards

- Nature
- Philosophical Magazine
- Philosophical Transactions of the Royal Society of London
- Physical Review
- Physics of Fluids
- Planetary and Space Science
- Proceedings of the IEEE
- Proceedings of the Royal Physical Society of London
- Radio Science
- Reviews of Geophysics
- Reviews of Geophysics and Space Physics
- Reviews of Modern Physics
- Quarterly Journal of Mechanics and Applied Mathematics
- Quarterly Journal of the Royal Meteorological Society
- Quarterly Review
- Science
- Soviet Physics Acoustics
- Tellus
- The Journal of the Acoustical Society of America
- The Journal of Aeronautical Science
- The Journal of Geophysical Research

Section 2.0 of the report presents the annotated bibliography in which the papers are arranged in an approximate chronological order. There are two appendices. Appendix A reproduces the **"Bibliography of Infrasonic Waves"** which was published in the 1971 Volume 26 special issue on infrasonics and atmospheric acoustics published by The Geophysical Journal of the Royal Astronomical Society. Appendix B reproduces a list of references provided in *Gossard and Hooke's* 1975 book: **WAVES IN THE ATMOSPHERE: Atmospheric Infrasound and Gravity Waves - their Generation and Propagation**.

2.0 ANNOTATED BIBLIOGRAPHY

O. Reynolds, **"On the Refraction of Sound by the Atmosphere,"** Proc. Roy. Soc. 22, 531 (1874).

Abstract: My object in this paper is to offer explanations of some of the more common phenomena of the transmission of sound, and to describe the results of experiments in support of these explanations. The first part of the paper is devoted to *action of wind upon sound*. In this part of the subject, I find that I have been preceded by Professor Stokes, who in 1857 gave precisely the same explanation as that which occurred to me. I have, however, succeeded in placing the truth of this explanation upon an experimental basis; and this, together with the fact that my work upon this part of the subject is the cause and foundation of what I have to say on the second part, must be my excuse for introducing it here. In the second part of the subject I have dealt with the effect of the atmosphere to refract sound upwards, an effect which is due to the variation of temperature, and which I believe has not hitherto been noticed. I have been able to show that this refraction explains the well-known difference which exists in the distinctness of sounds by day and by night, as well as other differences in the transmission of sound arising out of circumstances such as temperature; and I have applied it in particular to explain the very definite results obtained by Professor Tyndall in his experiments off the South Foreland.

J.W.S. Rayleigh, **The Theory of Sound**: **Volume II**, The Macmillan Company, New York, (1896). Republished by Dover Publications, New York, (1945).

E.H. Barton, **"On the Refraction of Sound by Wind,"** Quarterly Review 452, 159 (1901).

Abstract: In his treatise on Sound (vol. ii. pp. 132-4), Lord Rayleigh discusses the refraction of sound by wind where the rays are everywhere but slightly inclined to the wind, and obtains an approximate expression which, in the numerical illustration adduced, gives a result differing by only a few minutes of arc from the strict value. The theoretical interest of the wave propagation in this case seems, however, to warrant a slightly fuller examination of the problem on the basis of Huygens principle of wavelets and envelopes. Let us retain Lord Rayleigh's assumption as to the distribution of the wind, namely, that it is everywhere horizontal and does not vary in any one horizontal plane but is different at different levels. Then, confining our examination to rays in the same vertical plane as the wind, we find the following results:--

(1) The direction of propagation is not usually at right angles to the wave-front where there is a wind, consequently the cosecant law for the wave-front needs supplementing by another expression giving the direction of the ray.

(2) Total reflection cannot occur if the wave-front is initially horizontal.

(3) In a region where the horizontal wind increases uniformly as we ascend, the rays instead of forming a catenary describe a more complicated curve which, however, reduces to a parabola in the special case of rays whose wave-fronts are horizontal.

H. Lamb, **"On the Theory of Waves Propagated Vertically in the Atmosphere,"** London Math. Soc. 7, 122 (1909). [December]

Abstract: This question has been treated by Poisson (1807) and Lord Rayleigh (1890). The more definite results so far obtained relate to simple-harmonic vibrations; they

presuppose, moreover, isothermal conditions, both as to the equilibrium state and as to the variations of density which constitute the waves. I have attempted to carry the matter a little further. Beginning with the case of an isothermal atmosphere, by assuming the oscillations of density to follow the adiabatic law, I examine the propagation of an arbitrary disturbance. The effect of viscosity is also discussed. Finally, some calculations are given relating to an atmosphere which has a uniform gradient of temperature (diminishing upwards), and is therefore of finite height.

Owing to the indefinite increase of amplitude as the waves travel upwards, which (as will appear) viscosity is not able to check altogether to check, the results are not in all respects to be interpreted too literally. The investigation may, however, have an independent interest as a study of wave-propagation in a variable medium under conditions which are not artificially imagined, but are such as naturally present themselves. One unexpected result may possess a definite natural period of vibration, in the sense that an impressed local periodic *force* of this (but of no other) period would generate an oscillation of continually increasing amplitude The case is, however, not wholly analogous to that of the free vibrations of a finite dynamical system, for the order of the infinity is different, and the exaggerated amplitude is not produced by an enforced local vibration of prescribed amplitude, even if this have exactly the period in question.

H. Lamb, **"On Atmospheric Oscillations,"** Proc. Roy. Phys. Soc. 84A, 551 (1911).

Abstract: The chief question discussed in this paper is that of the free oscillations of an atmosphere whose temperature varies with the altitude; and in particular the case of a uniform vertical temperature-gradient is studied in some detail. For consistency it is assumed that the expansions and contractions follow the adiabatic law. The problem is treated as a two dimensional one, the space coordinates involved being horizontal and vertical; and the more definite conclusions arrived at relate to the case where the (horizontal) wave-length is somewhat large in comparison with the height of the atmosphere.

The results are most easily interpreted when the temperature-gradient does not fall much below that characteristic of convective equilibrium. The normal modes of oscillation then fall into well-defined types.

E.A. Milne, **"Sound Waves in the Atmosphere,"** Phil. Mag. 42, 96 (1921).

Abstract: By an application of a general principle of propagation the equations of propagation of sound waves in a medium in which the velocity and the velocity of sound are given functions of positions are obtained in a general form; they are in two sets, one expressing the convection at each point and the other the refraction. By means of the simplified forms appropriate to a stratified medium such as the atmosphere, expressions are given for the corrections to the apparent bearing and elevation of a source of sound, and Hill's approximate formulae in terms of the mean wind and temperature lapse are deduced. The range of audibility of an aerial source of sound as limited by total reflexion is then considered; the conditions for limited range are obtained and curves of extreme audibility are calculated. It is pointed out that if the total reflexion of the boundary ray occurs at an intermediate height and not at the ground, then the boundary ray need not have a zero angle of descent, and the apparent elevation of the source may be non-zero at all ranges. Finally, the conditions for the existence of an envelope to the totally reflected rays are obtained, and the nature of the envelope and of the locus of the vertices of the rays are examined in particular cases.

F.A. Lindeman and G.M.B. Dobson, **"A Theory of Meteors, and the Density and Temperature of the Outer Atmosphere to which it Leads,"** Proc. Roy. Soc. 102, 411 (1923).

Abstract: None.

Unknown, **"The Oldebroek Explosion of October 28, 1922,"** Nature 111, 32 (1923). [January]

Abstract: None.

F.J.W. Whipple, **"The High Temperature of the Upper Atmosphere as an Explanation of Zones of Audibility,"** Nature 111, 187 (1923). [February]

Abstract: None. Paper points out that increase in temperature in upper atmosphere pointed out by *Lindeman and Dobson* (1923) from studies of meteors, provides an explanation of zones of audibility and silence surrounding "scenes of great explosions".

G.I. Taylor, **"Waves and Tides in the Atmosphere,"** Proc. Roy. Soc. 126A, 169 (1929).

Abstract: None.

F. J. W. Whipple, **"The Great Siberian Meteor and the Waves, Seismic and Aerial, Which it Produced,"** Quart. J. Royal Meteorological Society 56, 287 (1930).

Abstract: None.

G.I. Taylor, **"The Oscillations of the Atmosphere,"** Proc. Roy. Soc. 156A, 318 (1936).

Abstract: It is shown that when the temperature of the atmosphere is a function only of height above the ground, free oscillations are possible which are identical with those of a sea of uniform depth H, except that the amplitude of the oscillations is a function of the height. The equivalent depth H is related to the velocity V of straight long waves in a non-rotating atmosphere by the relation $V^2 = gH$. There are in general an infinite number of possible velocities V at which long waves can travel. In general, therefore, there is an infinite number of equivalent depths, H, but in the special case of convective equilibrium there is only one.

The existence of an equivalent depth was conjectured by Laplace, who confirmed his conjecture in the special case of convective equilibrium when $\gamma = 1$. Lamb extended the proof to cover convective equilibrium with other values of V, but no other cases had been solved. Jeffreys and Bartels have given definite integrals for finding this depth, though they have not proved that the atmosphere can oscillate like a sea of uniform depth. Other workers have doubted the existence of an equivalent depth except in the special case mentioned above. It is a corollary to the present work that no integrals of the type proposed by Jeffreys (for the case when the temperature during an oscillation remains constant while

the pressure varies) or Bartels can give any of the (in general) infinite number of equivalent depths.

C.L. Pekeris, "**Atmospheric Oscillations,**" Proc. Roy. Soc. 158A, 650 (1937).

Abstract: It is shown that when the increase of temperature between 30 and 60 km which was inferred by Whipple from the anomalous propagation of sound waves, is assumed it is possible to find a temperature distribution above 60 km such that the atmosphere has a free oscillation of a period very close to 12 solar hours. In this oscillation there is a horizontal nodal surface at about 30 km height at which the velocities and pressure variations vanish, the atmospheres below and above this level swinging in opposite directions. The amplitudes of the velocities, which are mainly horizontal, at the 100 km level are about 200 times larger that at the ground. These two features of the free oscillation remove two difficulties which Chapman encountered in his interpretation of the diurnal variation of the earth's magnetic field by the "dynamo" theory, namely (a) that the pressure oscillation in the conducting layer, where the dynamo effect is produced, is nearly 180° out of phase with the observed pressure oscillation at the ground, and (b) that the required electrical conductivity of the conducting layer is larger than the value that can be inferred from radio soundings.

It is also found that the atmosphere has another mode of free oscillation, of a period of 10 1/2 hours and having no nodal surfaces. The existence of this mode of free oscillation is required by the evidence from the propagation of long waves which was put forth by G.I. Taylor. Taylor has proved that one can determine the period of free oscillation of the atmosphere from the speed of long waves. Now the wave which was caused by the Krakatau eruption in 1883 and which went round the world several times was propagated with a speed which corresponds to a period of free oscillation of about 10 1/2 hours. A similar speed was found by Whipple for the wave of the Great Siberian Meteor.

A method is given for determining the forced tidal oscillation of a horizontally uniform atmosphere on a rotating globe, and is applied to the atmosphere mentioned above. It is found that the existence of the semi-diurnal free oscillation restricts in some measure the possible temperature distribution in the upper atmosphere.

C.L. Pekeris, "**The propagation of a pulse in the atmosphere,**" Proc. Roy. Soc. 171A, 434 (1939).

Abstract: It is shown that in a composite atmosphere, such as was assumed in a previous paper in connexion with the theory of atmospheric tides, a surface pulse would excite waves of the first and second modes of oscillation, the amplitude of the former being greater than that of the latter by a factor varying from 2.4 to 2.9. This factor would tend to increase on account of dispersion. Some records of the atmospheric wave which was caused by the Krakatoa eruption of 1883 are discussed with a view to identifying the nature of the second mode. There are indications of this wave in the first passage and, to a lesser degree, in the second passage. The energy of these waves is estimated to be of the order of 10^{24} ergs. In the appendix is given a distribution with height of the vertical velocities in the two modes of oscillation of a model atmosphere. At heights of the order of 100 km, these velocities are found to be in phase with the surface pressure for *both* modes.

B. Haurwitz, "**The Propagation of Sound Through the Atmosphere,**" J. Aero. Sci. 9, 35 (1941). [December]

Abstract: This article gives an elementary survey of the geometrical laws to which sound propagation through the atmosphere is subjected. In a calm atmosphere with decreasing temperature upward, the sound rays are bent upward. If the sound ray returns to the ground, the temperature must increase upward. A wind which becomes stronger with the elevation bends the sound ray back to the ground in the direction of the wind but increases the upward curvature of sound ray in the opposite direction. This, a region of audibility around a source of sound must be asymmetrical if it is due to the wind. Due to the curvature of the sound rays, aircraft can only be heard within a region well above the visual horizon, to so-called acoustical bowl. The zones of anomalous audibility around an explosion which are separated from the region of normal audibility by zones of silence are to be explained by high air temperatures, of about 340^{o} absolute or more, at around 40-50 km, altitude.

B. Gutenberg, **"Propagation of Sound Waves in the Atmosphere,"** J. Acoust. Soc. Am. 13, 151 (1942). [October]

Abstract: The effect of humidity on the velocity of sound waves is investigated (Eq. (5) Table I). The radius of curvature for a ray of sound which is propagated in the direction of the wind is given [Eq. (13)] and discussed. The amplitudes of sound waves as a function of the distance are given [Eq. (17)], and the relative importance of the quantities involved is discussed.

F.L. Whipple, **"Meteors and the Earth's Upper Atmosphere,"** Rev. Mod. Phys. 15, 246 (1943). [October]

Abstract: None.

J.S. Saby and W.L. Nyborg, **"Ray Computation for Non-Uniform Fields,"** J. Acoust. Soc. Am. 18, 316 (1946). [October]

Abstract: A formula is derived which simplifies the computation and tracing of rays in non-uniform sound fields. In applying it, a field is first assumed to be equivalent to an array of horizontally homogenous strata each with a uniform gradient of the speed of sound. Then the "range" of the ray through the whole array can be computed by the formula in *one step*, rather that several, to a degree of approximation considered adequate for many experimental situations. Special problems encountered in applying the formula under certain types of conditions are discussed. The method is particularly useful in the study of propagation of ultrasonic waves through the atmosphere near the ground, where meteorological conditions often produce rather complicated gradient conditions.

D. Blokhintzev, **"The Propagation of Sound in an Inhomogeneous and Moving Medium I,"** J. Acoust. Soc. Am. 18, 322 (1946). [October]

Abstract: In this paper the wave equations for the propagation of sound in an inhomogeneous and moving medium are established (Section I). In Section II special cases are considered and a generalization of Kirchhoff's theorem (Huygens' principle) is given for a moving medium. In Section III the general equations of acoustics are considered in the approximation of geometrical acoustics. And finally, in Section IV the equations are generalized for the case of a medium containing a salt solution (sea water).

D. Blokhintzev, **"The Propagation of Sound in an Inhomogeneous and Moving Medium II,"** J. Acoust. Soc. Am. 18, 329 (1946). [October]

Abstract: In the present paper several applications of the theory developed in Part I are set forth. Section I deals with the propagation of sound in a turbulent medium. Section II with its propagation through a shock wave.

P. Rothwell, **"Calculation of Sound Rays in the Atmosphere,"** J. Acoust. Soc. Am. 19, 205 (1947). [January]

Abstract: None. The paper deals with the acoustic location of aircraft.

K. Weeks and M.V. Wilkes, **"Atmospheric oscillations and the resonance theory,"** Proc. Roy. Phys. Soc. 192A, 80 (1947).

Abstract: The first part of the paper describes the circumstances under which tidal energy supplied to the atmosphere through the action of tide-producing forces can be trapped between a certain stratum (usually where the temperature has a minimum) and the ground. The results are then applied to discuss in general terms the types of free oscillations which an atmosphere with a given temperature distribution may possess. It is pointed out that Kelvin's hypothesis that the atmosphere has a resonance in the neighborhood of 12 solar hours leads directly to the conclusion that the temperature must fall again to a low value at some level above the hot region inferred from observations of the anomalous propagation of sound.

In the second part of the paper results are given of numerical calculations made with the aid of differential analyzer to determine to what extent the requirements of the resonance theory restrict the possible temperature variations in the atmosphere. The results of Appleton and Weeks (1939) on lunar tides in the E region are discussed, and it is shown that there is no difficulty in reconciling them with oscillation theory provided a suitable temperature distribution in the E region is assumed.

E. Cox, **"Microbarograph Pressures from Large High Explosive Blasts,"** J. Acoust. Soc. Am. 19, 832 (1947). [September]

Abstract: Charges detonated for Army-Navy Explosive Safety Board tests in Idaho, October 1946, produced pressure waves recorded by subsonic frequency microbarographs at distances 12.9 to 452 km. Observations showed both normal and abnormal signals at 182 and 292 km, no clear abnormal signals at 141 or 89 km, no signals of any kind at 872 km. In the zone of normal audibility, average wave velocity between blast points and receiving station decreases slightly with increasing distance, and may increase slightly with charge weight; it is substantially the same as sound velocity. No consistent travel-time differences for the abnormal signals resulted from changing charge weight between 3.2 and 250 tones TNT. Neither normal nor abnormal signal strengths were predictable from charge weight. The largest abnormal signal properly recorded was a 3-cycle wave train with peak-to-peak amplitude 220 microbars received 182 km from a 125-ton blast. Interpolated to apex pressure perturbation, this signal amplitude eliminates shock wave supersonic velocity as a logical explanation for abnormal audibility. Incident angles of abnormal rays are not calculable. However, if one assumes 182 km as the descent distance for rays starting out horizontally, neglects wind effects, and accepts the apex temperature

measured by balloons, rough calculations of lower stratosphere temperatures are possible. This establishes 34 km as a minimum altitude at which ground temperature is reached.

C.L. Pekeris, **"The Propagation of a Pulse in the Atmosphere. Part II,"** Phys. Rev. 73, 145 (1948). [January]

Abstract: The previous investigation of the dispersion of long waves in the atmosphere has been extended to shorter periods of the order of one minute. Both the phase velocity and group velocity have been determined. The results are applied to the interpretation of the pressure wave produced by the Great Siberian Meteor and to the pressure oscillations recorded by microbaragraphs in England.

E.F. Cox, **"Abnormal Audibility Zones in Long Distance Propagation through the Atmosphere,"** J. Acoust. Soc. Am. 21, 6 (1949). [January]

Abstract: Five thousand tons of high explosives detonated on Helgoland, April 18, 1947, created air pressure perturbations recorded on microbarographs between 66 and 1000 km SSE from the blast. Instruments responded to frequencies 0.05 - 5 c.p.s. Arrival times of abnormal signals at six stations more distant than 200 km, supplemented by high altitude meteorological data calculations. Temperatures agree with N.A.C.A. values up to 42 km, but show a reduced gradient above that altitude, and maximum value 294°K in the temperature hump between 30 and 70 km. This temperature maximum establishes a critical ray which is refracted to infinity. A new explanation for observed outer boundaries of abnormal zones is therefore proposed, and substantiated by recorded evidence of dispersion near the temperature maximum. In the signal received near the abnormal zone outer boundary, high frequency content predominates.

M.V. Wilkes, **Oscillations of the Earth's Atmosphere**, Cambridge University Press, Cambridge, England, (1949).

R.S. Scorer, **"Numerical Evaluation of the Form:** $I = \int_{x_1}^{x_2} dx\, f(x)\, e^{i\phi(x)}$ and the Tabulation of the Function - $Gi(z) = \frac{1}{\pi}\int_0^\infty \sin(uz + \frac{1}{3}u^3)\, du$, Quart. J. Mech. App. Maths. 3, 107 (1950).

Abstract: This type of integral often occurs in the calculation of the wave form due to a source in a dispersive medium. The principle of a stationary phase is used to evaluate it in terms of the Airy Integral, of which tables are published, and of

$$Gi(z) = \frac{1}{\pi}\int_0^\infty \sin(uz + \frac{1}{3}u^3)\, du.$$

A table is given of this function for z>0 and of a closely associated function for z<0. In a separate note by Dr. J.C.P. Miller it is shown that these, together with the published tables of the Airy Integral, provide the solution of the differential equation

$$\frac{d^2y}{dz^2} - zy = P(z),$$

where P(z) is a polynomial or a power series.

R.S. Scorer, "**The dispersion of a pressure pulse in the atmosphere,**" Proc. Roy. Soc. A201, 137 (1950). [March]

Abstract: The object is to find what pressure oscillations would be observed on the ground at a great distance from an explosion. The explosion is represented mathematically by a Fourier integral, corresponding to the introduction of a large volume into the atmosphere at a point on the ground. The resulting pulse is calculated for various distances for a model atmosphere consisting of a troposphere with a constant lapse-rate of temperature and an isothermal stratosphere. It is composed of those oscillations that can be propagated horizontally as gravity waves in this model atmosphere, namely, those of period exceeding a cut-off period of 111 sec. The pulse consists of a series of waves of decreasing amplitude and period, terminating with a period of 12.7 sec.

The results are compared with the oscillations observed on the occasion of the fall of the Great Siberian Meteorite and the energy which it is estimated to have communicated to the atmosphere is about 4 x 10^{24} ergs only a fraction of which resided in the gravity wave. Neglect of the warmer layers in the higher levels in the stratosphere means that the calculated pulse terminated too soon, and a second series of waves of considerable amplitude and of greater frequency is completely absent. The form of these has not been calculated because of the prohibitive amount of computing involved.

G.I. Taylor, "**The formation of a blast wave by a very intense explosion I. Theoretical discussion,**" Proc. Roy. Soc. A201, 159 (1950). [March]

Abstract: This paper was written early in 1941 and circulated to the Civil Defense Research Committee of the Ministry of Home Security in June of that year. The present writer had been told that it might be possible to produce a bomb in which a very large amount of energy would be released by nuclear fission-the name atomic bomb had not then been used-and the work here described represents his first attempt to form an idea of what mechanical effects might be expected if such an explosion could occur. In the then common explosive bomb mechanical effects were produced by the sudden generation of a large amount of gas at a high temperature in a confined space. The practical question which required an answer was: Would similar effects be produced if energy could be released in a highly concentrated form unaccompanied by the generation of gas? This paper has now been declassified, and though it has been superseded by more complete calculations, it seems appropriate to publish it as it was first written, without alteration, except for the omission of a few lines, the addition of this summary, and a comparison with some more recent experimental work, so that the writings of later workers in this field may be appreciated.

An ideal problem is here discussed. A finite amount of energy is suddenly released in an infinitely concentrated form. The motion and pressure of the surrounding air is calculated. It is found that a spherical shock wave is propagated outwards whose radius R is related to the time t since the explosion started by the equation

$$R = S(\gamma) t^{\frac{2}{5}} E^{\frac{1}{5}} (\rho_0)^{-\frac{1}{5}},$$

where ρ_0 is the atmospheric density, E is the energy released and $S(\gamma)$ a calculated function of γ, the ratio of the specific heats of air.

The effect of the explosion is to force most of the air within the shock front into a thin shell just inside that front. As the front expands, the maximum pressure decreases till, at about 10 atm., the analysis ceases to be accurate. At 20 atm. 45% of the energy has be degraded into heat which is not available for doing work and used up in expanding against atmospheric pressure. This leads to the prediction that an atomic bomb would be only half as efficient, as a blast producer, as a high explosive releasing the same amount of energy.

In the ideal problem the maximum pressure is proportional to R^{-3}, and comparison with the measured pressures near high explosives, in the range of radii where the two might be expected to be comparable, shows that these conclusions are borne out by experiment.

G.I. Taylor, **"The formation of a blast wave by a very intense explosion. II. The atomic explosion of 1945,"** Proc. Roy. Soc. A201, 175 (1950). [March]

Abstract: Photographs by J.E. Mack of the first atomic explosion in New Mexico were measured, and the radius, R, of the luminous globe or 'ball of fire' which spread out from the centre was determined for a large range of values of t, the time measured from the start of the explosion. The relationship predicted in part I, namely, that $R^{5/2}$ would be proportional to t, is surprisingly accurately verified over a range from R=20 to 185 m. The value of $R^{5/2}t^{-1}$ so found was used in conjunction with the formulae of part I to estimate the energy E which was generated in the explosion. The amount of this estimate depends on what value is assumed for γ, the ratio of the specific heats of air.

Two estimates are given in terms of the number of tons of the chemical explosive T.N.T. which would release the same energy. The first is probably the more accurate and is 16,800 tons. The second, which is 23,700 tons, probably overestimates the energy, but is included to show the amount of error which might be expected if the effect of radiation were neglected and that of high temperature on the specific heat of air were taken into account. Reasons are given for believing that these two effects neutralize one another.

After the explosion a hemispherical volume of very hot gas is left behind and Mack's photographs were used to measure the velocity of rise of the glowing centre of the heated volume. This velocity was found to be 35 m./sec.

Until the hot air suffers turbulent mixing with the surrounding cold air it may be expected to rise like a large bubble in water. The radius of the 'equivalent bubble' is calculated and found to be 293 m. The vertical velocity of a bubble of this radius is $(2/3)[29{,}300g]^{1/2}$ or 35.7 m./sec. The agreement with the measured value, 35 m./sec., is better than the nature of the measurements permits one to expect.

A.P. Crary, **"Stratosphere Winds and Temperatures from Acoustical Propagation Studies,"** J. of Meteor. 7, 233 (1950). [June]

Abstract: An investigation of the velocities of compressional waves in the region 30 to 60 km above sea level has been conducted by means of sound-propagation tests. From an analysis of these tests, knowledge of stratosphere winds and temperatures is obtained. A separation of the temperature and wind effects is made possible by variations in the distances and azimuths of the recording sites from the source of the waves. Results of summer tests in the Canal Zone, Bermuda, and Alaska, and of a winter test in Alaska, together with some results of incomplete tests on the east coast of the United States and in New Mexico, are presented. Temperatures were found to be less than those reported in earlier acoustical studies, where winds were assumed to be negligible. The height of the high-temperature layer varied between 50 and 60 km, being greatest in high latitudes in

winter. Easterly winds were found during the summer months for all latitudes, with minimum values in Alaska; high westerly winds were found in Alaska during the winter. Diurnal effects are shown to have been negligible.

F.B. Daniels, **"On the Propagation of Sound Waves in a Cylindrical Conduit,"** J. Acoust. Soc. Am. 22, 563 (1950). [September]

Abstract: The characteristic impedance and propagation constant of a cylindrical conduit are calculated on the basis of an equivalent electrical T-section. Numerical values of the results are plotted for air at 20°C, for a range of values of the independent variable which includes the region of transition from isothermal to adiabatic conditions.

G.B. Olmsted, **"OPERATIONS BUSTER AND JANGLE - Project 7.6 BUSTER and Project 7.3 JANGLE: Detection of Airborne Low-Frequency Sound from the Atomic Explosions of Operations Buster and Jangle,"** USAF Office for Atomic Energy (AFOAT-1) Report, March 15, 1952. [March]

Abstract: Measurements of the airborne low-frequency sound from the atomic explosions of Operations BUSTER and JANGLE (October and November, 1951) were made at ten locations covering a variety of directions and distances from the Nevada Test Site in order to determine the range and reliability of acoustic long-range detection equipment. The Surface test (1.2 KT) was detected at least to 2818 km (1520 naut. mi.); tests Baker (3.5 KT), Charlie (14 KT), Easy (31 KT) and the underground test (1.2 KT) to 3670 km (1980 naut. mi.); and test Dog (21 KT) to 4400 km (2370 naut. mi.) from the Test Site. Transmission toward the east was better than toward the west, confirming expectations of seasonal effects in propagation. Results indicate the feasibility of acoustic techniques to detect and locate distant atomic explosions of various calibers detonated in the air, on the ground, or shallow underground. Further measurements during subsequent atomic tests are recommended.

J.M. Richardson and W.B. Kennedy, **"Atmospheric Winds and Temperatures to 50-Kilometers Altitude as Determined by Acoustical Propagation Studies,"** J. Acoust. Soc. Am. 24, 731 (1952). [November]

Abstract: An average of three measurements per month of upper atmosphere winds and temperatures was made during the period July 21, 1950 through May 31, 1951 by means of acoustical propagation studies. Field operations were centered in Wray, Colorado (40° N. lad, 102° W. long) and extended radially 200 km. A variation in azimuth and distance from sound source to recorder positions permitted the separation of wind and temperature components of the observed upper atmosphere sonic velocity gradients. It was found that upper winds were generally westerly and of large magnitude during the winter (autumnal to vernal equinox) and easterly and of small magnitude during the summer, with wide fluctuations during the equinoctial periods. Short-term fluctuations in the wind vector were observed to be of the same order of magnitude as the vector itself. The short-term fluctuation is now well established. A doubly-periodic annual variation in temperature was observed above 25-km altitude, with mean value in agreement with accepted NACA values.

U. Ingard, **"A Review of the Influence of Meteorological Conditions on Sound Propagation,"** J. Acoust. Soc. Am. 25, 405 (1953). [May]

Abstract: The study of the different atmospheric effects indicates that in short-range sound propagation the attenuation by irregularities in the wind structure (gustiness) often is of major importance in comparison with humidity, fog, and rain, and ordinary temperature and wind refraction. However, the ground attenuation can be of equal importance to the gustiness, in particular, when the sound source and the receiver are sufficiently close to the ground. The effect on the attenuation of the height of the source and the receiver off the ground is presented as a function of frequency for a typical ground impedance. The attenuation curve exhibits a maximum which in most cases lies at a frequency between 200 and 500 Hz.

C.T. Johnson and F.E. Hale, "**Abnormal Sound Propagation Over the Southwestern United States,**" J. Acoust. Soc. Am. 25, 642 (1953). [July]

Abstract: Abnormal propagation of sound in the east-to-west and west-to-east directions has been studied throughout a period of a year. Experiments were carried out over the California-Arizona desert using explosions of 1200 pounds of TNT. Returns of sound from altitudes of 30 to 50 km were consistently received to the east in winter and to the west in summer. Sounds which traveled to the high temperature region at 80 to 100 km altitude were received about one-fifth of the time. Sounds were returned from the second region somewhat better to the east in summer and to the west in winter. Sounds were returned from the second region somewhat better to the east in summer and to the west in winter. An early arriving abnormal wave was received at ranges greater than 400 km.

E. Gossard and W. Munk, "**On Gravity Waves in the Atmosphere,**" J. Meteor. 11, 259 (1954). [August]

Abstract: Seven times in a year's continuous observations, marked oscillations with periods from 5 to 15 minutes were simultaneously recorded on a barograph and a damped anemometer located at La Jolla, California. The oscillations often followed a reversal of the land- and sea-breeze regime, and they were sometimes preceded by a pressure pulse. Perturbations of pressure (p) and wind speed (v) attain double amplitudes up to several millibars and several meters per second, respectively, with maximum pressure occurring at the time of maximum "orbital" wind. This suggests propagating gravity waves in the atmosphere. Their velocity (C) can be inferred from the La Jolla according to the impedance relationship, $p=\rho vC$; the computed arrival time at Point Loma, 11 miles to the south, agrees with the recorded arrival. Phase velocities are of the order of 10 m/s and greatly exceed ambient winds. Wavelengths range from 4 to 10 kilometers. A slight effect on sea level is apparant. Under steady meteorological conditions, there is good coherence for at least four wavelengths in the direction of propagation, but less coherence at right angles to this direction. The wave crests appear to be oriented normal to the wind shear between the upper and lower winds. The observed wave velocity is of the order given by the shallow "water" theory, i.e., $(gh\Delta \ln\theta)^{1/2}$, where h is the elevation of the inversion layer, and $\Delta \ln\theta$ is the logarithmic change in potential temperature across this layer. The observed period is not inconsistent with the period $2\pi/s$ of the fundamental mode of the least dispersive (longest) "trapped" waves, where $s^2 = gd(\ln\theta)/dz$ is a measure of the stability *above* the inversion layer.

D.C. Pridmore-Brown and U. Ingard, **"Sound Propagation into the Shadow Zone in a Temperature-Stratified Atmosphere above a Plane Boundary,"** J. Acoust. Soc. Am. 27, 36 (1955). [January]

Abstract: The sound field in the "shadow zone" (diffraction region) formed over a plane boundary in an atmosphere with a constant vertical temperature gradient is analyzed both theoretically and experimentally. The boundary condition at the plane is given by a normal acoustic impedance independent of the angle of incidence. As in the corresponding problem of underwater sound where the boundary is a pressure release surface, it is found that the major portion of the sound pressure in the shadow zone decays exponentially with distance at a rate proportional to the one-third power of frequency and two-thirds power of temperature gradient. The effect of boundary impedance enters mainly through its resistive component. The rate of sound decay for pressure release boundary (zero impedance) is found to be 2.3 times that for a rigid boundary (infinite impedance).

Sound pressure measurements in the shadow zone in a laboratory chamber in which a large temperature gradient was created were made for both hard and absorbing boundaries, and the results were found in essential agreement with theory.

F. Press and J. Oliver, **"Model Study of Air-Coupled Surface Waves,"** J. Acoust. Soc. Am. 27, 43 (1955). [January]

Abstract: Flexural waves generated in a thin plate by a spark source are used to investigate properties of air-coupled surface waves. Both ground shots and air shots are simulated in the model. Effects of source elevation, fetch of air pulse, and cancellation by destructive interference are studied.

W. Goldsmith and W.A. Allen, **"Graphical Representation of the Spherical Propagation of Explosive Pulses in Elastic Media,"** J. Acoust. Soc. Am. 27, 47 (1955). [January]

Abstract: The problem of spherically symmetric wave propagation in homogeneous, isotropic elastic media of infinite extent has been examined frequently in recent years, and a number of analytical solutions have been reported in the literature for various initial conditions. Some interest has also been exhibited in the application of these relations to the transient phenomena occurring in metals when subjected to contact explosions. Under these conditions, an actual wave system can be approximated by postulating the existence of a spherical cavity in the interior of the medium and applying as the initial condition a pulse of exponentially decaying character. While no difficulty is encountered here in an analytic expression of the displacements, velocities and stresses occurring at each point of the medium as a function of location and time, it has been found highly desirable to represent these terms in pictorial form to permit a rapid evaluation of the nature of the disturbances in the region of interest. Consequently, numerical calculations have been performed on an IBM machine and the resultant data have been employed in a space-time representation of these parameters.

G.B. Olmsted, **OPERATION CASTLE (Project 7.2): Detection of Airborne Low-Frequency Sound From Nuclear Explosions,"** USAF Office for Atomic Energy Report, May (1955).

Abstract: Measurements of the airborne low-frequency sound from the Operation CASTLE nuclear explosions were made at 15 remote locations, covering a variety of

distances and directions from the Pacific Proving Grounds, with the objective of studying the relation between signal characteristics and the energy released over the range of yields from 1 to 15 megatons equivalent. Both standard and very low-frequency sound recording equipment responsive to small atmospheric pressure variations in the frequency range from 1/0 to 0.002 cycles/second were employed. Signals were detected at ranges exceeding 45,000 km for explosions larger than 5 MT, 30,000 km for the 1.7 MT shot, and 10,000 km for the 0.12 MT shot. All megaton shots produced the initial dispersive wave train of very-low frequency previously noted for IVY MIKE.

R. Yamamoto, **"The Microbarograph Oscillations Produced by the Explosions of Hydrogen Bombs in the Marshall Islands,"** Bull. Am. Met. Soc. 37, 406 (1956). [October 8]

Abstract: Concerning the pressure oscillations due to the hydrogen-bomb explosions in the Marshall Islands, the records of routine barographs at the fourteen stations in the Pacific territory were examined and the following facts were found: (1) No trace of the oscillation could be detected on the barograms at the stations located nearly to the west of the explosion site n spite of comparatively close distance. (2) Speed of the wave propagating eastwards was higher than that of the westward wave by about 50 m/sec.

F. Codero, H. Matheson, and D.P. Johnson, **"A Nonlinear Instrument Diaphragm,"** J. Res. Nat. Bur. Stnd. 58, 333 (1957). [June}

Abstract: Details of fabrication for the production of sensitive diaphragms having a controlled nonlinear pressure-deflection characteristic are presented. The desired characteristic was such that when the diaphragm formed one plate of a condenser in the frequency-controlling network of a Wien-bridge oscillator, the resulting pressure-frequency transfer characteristic would be linear between -30 and +30 dynes per square centimeter. Typical transfer curves are shown.

G.V. Groves, **"Velocity of a body falling through the atmosphere and the propagation of its shock wave to earth,"** J. Atm. Terr. Phys. 10, 73 (1957).

Abstract: A solution is obtained for the velocity of a body falling to earth from a point outside the appreciable atmosphere on the assumption that (i) the flight path is a straight line inclined at an angle θ to the horizontal, (ii) the drag coefficient C_D is constant, (iii) gravitational acceleration g is constant within the atmosphere, and (iv) the scale height H of the atmosphere is constant. The motion is characterized by the single parameter $p^* = mg\sin\theta/SC_D$, where m is the mass and S the frontal cross-sectional area of the body. Graphs are presented showing velocity and deceleration against height for falls from 100, 200, and 300 km and for various values of p*. It is shown that the deceleration is greatest at heights were the atmospheric pressure is approximately 2/3 p* (provided maximum deceleration is somewhat larger than the gravity component along the trajectory). The maximum deceleration is shown to be approximately $[e^{-1}(E/gH+\log_e p^*)-0.5152]\sin\theta$ (provided the body falls at least two to three scale heights before reaching maximum deceleration), where E is the initial energy of the body and p* is measured in atmospheres.

The effect is considered of refraction arising from the temperature structure of the atmosphere on the shock wave generated by a vertically falling body. It is shown that only a part of the shock wave originating in the lower atmosphere will reach earth in the case of

falls from above 120 km: but for falls from below this height, an additional part of the shock wave originating in the region of the temperature maximum at 50 km may also reach earth. Curves are plotted showing the horizontal range from the impact point at which shock waves originating in the lower atmosphere reach earth for bodies falling vertically from 100, 200, and 300 km with various values of p*.

E. F. Cox, **"Far Transmission of Air Blast Waves,"** Phys. Fluids 1, 95 (1958). [March-April]

Abstract: A semi-acoustic theory of blast energy propagation, incorporating Sachs' scaling modified for altitude of observation, gives excellent agreement with experiments, providing Hillar's similarity principle is restricted to similar ambient (weather) conditions. Comparisons between this theory and experiments are made for free air (no reflections) blast pressures; ground-level blast pressures in an isothermal, still atmosphere; and blast pressures under a linear temperature inversion.

E.F. Cox, **"Sound Propagation in Air,"** in Handbuch der Physik, 48, Chapter 22, pp. 455-461, Springer-Verlag, Berlin, (1958).

Abstract: None

F.B. Daniels, **"Noise-Reducing Line Microphone for Frequencies below 1 cps,"** J. Acoust. Soc. Am. 31, 529 (1959). [April]

Abstract: A novel type of line microphone is described that utilizes a distributed input primarily for the purpose of improving signal-to-wind-noise ratio. The input to the transducer takes place through a tapered pipe that is coupled to the atmosphere by means of acoustical resistances uniformly spaced along the length of the pipe. The relationship between resistances of the openings and the longitudinal variation in the characteristic impedance of the pipe is so adjusted as to make the system nonreflecting. Microphones of this type have been constructed for use in the frequency range below 1 cps for the purpose of studying atmospheric pressure oscillations in this range. A prototype, 1980 ft long with 100 openings, which gives an improvement in the signal-to-noise ratio of as much as 20 db under severe wind conditions, is described.

J.N. Hunt, R. Palmer and W. Penney, **"Atmospheric Waves Caused by Large Explosions,"** Phil. Trans. Roy. Soc. London A252, 275 (1960).

Abstract: This paper considers the harmonic oscillations of several simple model atmospheres. The oscillations are of two types. In the first, the kinetic energy per unit volume tends to zero a great heights; in the second, the kinetic energy per unit volume remains finite. A large explosion at ground level excites a spectrum of both types of oscillation. The pulse ultimately separates into two parts-a train of travelling waves which can be observed at ground level at great distances, and a train of travelling waves which disappear into the upper atmosphere.

The complete range of experimental observations on the pressure oscillations caused by explosions of energies varying between 10^{20} and 10^{24} ergs can only be interpreted with model atmospheres having one or more sound channels, i.e., having at least one minimum in the temperature-height relationship of the atmosphere. In spite of the

complexity of the phenomena, the theory throws light on some of the characteristic features of the observations. The average period of the largest waves is roughly proportional to the cube root of the energy released by the explosion. The amplitudes of the waves from large explosions can be calculated. Conversely, good records enable the size of the explosion to be estimated.

The energy of the Siberian meteorite of 1908 was about 10^{16} cal, or 10 MT (T signifying a ton of t.n.t.).

C.O. Hines, **"Internal Atmospheric Gravity Waves at Ionospheric Heights,"** Can. J. Phys. 38, 1441 (1960).

Abstract: Irregularities and irregular motions in the upper atmosphere have been detected and studied by a variety of techniques during recent years, but their proper interpretation has yet to be established. It is shown here that many or most of the observational data may be interpreted on the basis of a single physical mechanism, namely, internal atmospheric gravity waves.

A comprehensive picture is envisaged for the motions normally encountered, in which a spectrum of waves is generated at low levels of the atmosphere and propagated upwards. The propagational effects of amplification, reflection, intermodulation, and dissipation act to change the spectrum continuously with increasing height, and so produce different types of dominant modes at different heights. These changes, coupled with an observational selection in some cases, lead to the various characteristics revealed by the different observing techniques. The generation of abnormal waves locally in the ionosphere appears to be possible, and it seems able to account for unusual motions sometimes observed.

E.E. Gossard, **"Spectra of Atmospheric Scalars,"** J. Geophys. Res. 65, 3339 (1960). [October]

Abstract: In Part 1 a wide-band spectrum of atmospheric pressure extending from periods of 1 week to 0.2 second is shown. The various frequency ranges are discussed with particular attention given to the midfrequency range. It is shown that convective activity and internal gravity waves can greatly modify the normal spectral distribution at midfrequencies and a specific example is discussed in detail. The amplitude spectrum of waves on the inversion layer is computed for this example from the surface pressure perturbations.

In Part 2 evidence is presented indicating that the spectra of passive scalars aloft show a systematic departure from the power law distribution to be expected for a fully developed internal subrange. The band of wave numbers analyzed in this report corresponds to scale sizes of 3 to 1000 feet. The 'energy' at the larger scales (small wave numbers) is quite variable and depends on altitude and atmospheric stratification. At the small scales of 10 to 100 feet is indicated. Very thin layers of exceptionally large mean-square fluctuation are found in regions of gradient of scalars.

V.H. Weston, **"The Pressure Pulse Produced by a Large Explosion in the Atmosphere,"** Can. J. Phys. 39, 993 (1961).

Abstract: The pressure pulse produced by a large explosion in the atmosphere is investigated. The explosion is represented in terms of the excess pressure and normal velocity of a closed surface, outside of which the hydrodynamical equations are linearized. The pulse is represented in terms of a Fourier transform of the associated harmonic

frequency problem, for which a ring-source Green's function is obtained in terms of an expansion of the discrete modes. It is shown that the excess pressure may be represented in terms of an integral (containing the Green's function) over the surface surrounding the source. The gravity wave portion of the pressure pulse at the ground is computed for various ranges from the source, which is located at various altitudes, and for three models of the atmosphere. In calculating the head o the pulse a new asymptotic technique is introduced which gives very good results for intermediate and long ranges.

N.F. Barber, **"The Directional Resolving Power of an Array of Wave Detectors,"** in Ocean Wave Spectra, Proc. of a Conference sponsored by the U.S. Naval Oceanographic Office and the National Academy of Sciences, Prentice-Hall, Englewood Cliffs, N.J., pp 137-150 (1961).

Abstract: None

Y.L. Gazaryan, **"Infrasonic Normal Modes in the Atmosphere,"** Sov. Phys. Acoust. 7, 17 (1961). [July-September]

Abstract: The results are given from numerical calculations of the characteristics of normal modes with periods greater than one minute for models of the atmosphere with one and two temperature minimums.

P. Chrzanowski, G. Greene, K.T. Lemmon and J.M. Young, **"Travelling Pressure Waves Associated with Geomagnetic Activity,"** J. Geophys. Res. 66, 3727 (1961). [November]

Abstract: Traveling atmospheric pressure waves with periods fro 20 to 80 seconds and pressure amplitudes from about 1 to 8 dynes/cm^2 have been recorded at a microphone station at Washington, D.C., during intervals of high geomagnetic activity. Trains of these waves can be expected at Washington from a quadrant approximately centered on north whenever the magnetic index K_p rises to a value above 5. Their horizontal phase velocity across the station is usually higher than the local speed of sound. During two 'red' auroras, clearly visible at Washington and at lower latitudes, the 20- to 80-second-period waves were accompanied by longer period, higher pressure, and much slower traveling pressure disturbances. Observational data on the wave systems are presented and discussed.

E.W. Carpenter, G. Harwood and T. Whiteside, **"Microbarograph Records from the Russian Large Nuclear Explosions,"** Nature 192, 857 (1961). [December]

Abstract: None. Paper is a single page long and presents microbarograph records from Soviet nuclear tests recorded in the U.K. at the Atomic Weapons Research Establishment, Foulness, Southbend-on-Sea, Essex.

G. Rose, J. Oksman, K. Kataja, **"Round-the-World Sound Waves produced by the Nuclear Explosion on October 30, 1961, and their Effect on the Ionosphere at Sodankyla,"** Nature 23, 1173 (1961). [December]

Abstract: None.

R.V. Jones, "**Sub-Acoustic Waves from Large Explosions,**" Nature 193, 229 (1962). [January]

Abstract: None.

E. Farkas, "**Transit of Pressure Waves through New Zealand from the Soviet 50 Megaton Bomb Explosion,**" Nature 193, 765 (1962). [February]

Abstract: None.

R. Araskog, U. Ericsson and H. Wagner, "**Long-range Transmission of Atmospheric Disturbances,**" Nature 193, 970 (1962). [March]

Abstract: None. Paper presents microbarograph data from Soviet explosions recorded in Sweden.

D.C. Pridmore-Brown, "Sound **Propagation in a Temperature- and Wind-Stratified Medium,**" J. Acoust. Soc. Am. 34, 438 (1962). [April]

Abstract: The general linearized equations governing the propagation of sound in a dissipationless temperature- and wind stratified medium are derived. A formal integral expression is given for the field of a point source located in such a medium, when it is bounded by an absorbing plane under conditions which lead to the formation of a shadow zone. This integral yields the following approximate (high-frequency) expression for the decay rate within the shadow

$$|p|^2 = \frac{B}{r} \exp\left[-(n/c)f^{1/2}(-c' - U'\cos\phi)^{2/3} r\right] .$$

Here p is the acoustic pressure, r is radial distance from the source, B is independent of r, f is frequency in cps, c is sound speed, c' and U' are sound- and wind-speed gradients at the ground surface, ϕ is the angle between the wind direction and the direction of sound propagation, and n is equal to 5.93 for a pressure release boundary and to 2.58 for a hard boundary.

R.L. Pfeffer, "**A Multi-layer Model for the Study of Acoustic-Gravity Wave Propagation in the Earth's Atmosphere,**" J. atmos. Sci. 19, 251 (1962). [May]

Abstract: An iterative numerical procedure, suitable for use on electronic computers, is presented for calculating the horizontal propagation speeds of acoustic gravity waves in a stratified atmosphere. The atmosphere is represented by an arbitrarily large series of isothermal layers, so that propagation can be readily studied in an atmosphere with a complex stratification. The basic approach is similar to that used in seismology. A sample calculation shows reasonable agreement with the exact two-layer solution of Pekeris.

R.L. Pfeffer and J. Zarichny, "**Acoustic-Gravity Wave Propagation from Nuclear Explosions in the Earth's Atmosphere,**" J. atmos. Sci. 19, 256 (1962). [May]

Abstract: In order to account for certain characteristic features of the atmospheric pressure oscillations produced by nuclear explosions, a numerical matrix method is used to solve the equations governing the horizontal propagation of acoustic-gravity waves in a stratified atmosphere. Solutions for various three-and four-layer models are found to be in qualitative agreement with the observations. In particular, they show normal (group velocity increasing with period) in the range of periods from 1 to 10 min and inverse dispersion (group velocity decreasing with period) at both shorter periods and, for some models, also a periods of the order of 5 to 15 min.

W.L. Donn and M. Ewing, **"Atmospheric Waves from Nuclear Explosions,"** J. Geophys. Res. 67, 1855 (1962). [May]

Abstract: Records of acoustic-gravity waves generated by multimegaton nuclear explosions which occurred between 1952 and 1961 are described. Atmospheric pressures recorded by sensitive instruments widely distributed over the earth are the basis of the analysis. The records begin with a dispersive wave train in which period decreases from a maximum of about 9 minutes to a minimum as low as 0.5 minute. Short-period waves which appear in the latter parts of the records and which often overlap the dispersive train are explained as belonging to higher modes. The method initiated by seismologists in the study of earthquake surface waves is used to compute group-velocity dispersion curves for the dispersive wave trains. These are compared with preliminary theoretical models for different thermal structures of the atmosphere. The empirical dispersion curves indicated that the atmospheric structure controlling the dispersion of these waves varies significantly along different profiles and probably along different segments of the same profile. The curves which best approach world-wide average atmospheric conditions seem to be those corresponding to meridional paths or those whose paths cause cancellation of the varying zonal winds.

W.L. Donn and M. Ewing, **"Atmospheric Waves from Nuclear Explosions-Part II: The Soviet Test of 30 October 1961,"** J. atmos. Sci. 19, 264 (1962). [May]

Abstract: Atmospheric waves from the Soviet nuclear test of 30 October 1961 are described for nine stations having wide global distribution. The records are characterized by waves which begin with the highest amplitudes and which show normal dispersion. These appear to be superimposed on a lower amplitude, long period train of waves which show inverse dispersion. As shown on dispersion curves of group velocity against period, a maximum of group velocity is indicated by the Airy phase formed through the merging of the two dispersive trains. A more prolonged train of waves of nearly uniform period is attributed to higher modes. The direct waves from the epicenter to the stations give dispersion curves that indicated significant variation in atmospheric structure along different azimuths and probably along different segments of the same azimuth. The curves for waves which have traveled more than once around the earth represent better sampling of world-wide atmospheric conditions and give better agreement with preliminary theoretical models. The average speed of the first arrivals is 324 m per sec, comparing well with the maximum obtained for the Krakatoa eruption.

V.H. Weston, **"The Pressure Pulse Produced by a Large Explosion in the Atmosphere. Part II,"** Can. J. Phys. 40, 431 (1962).

Abstract: The pressure pulse produced by a large explosion in the atmosphere is investigated. A realistic model for the vertical temperature is taken, with two temperature

ducts and the large temperature gradient in the thermosphere. The first three dominant modes or "free waves" are computed for the low-frequency range. The contribution of these modes to the head of the pressure pulse produced by a large explosion is calculated for a particular range. It is shown that the "high-frequency" phenomena previously observed is a superposition of relatively low-frequency modes. An increase in the altitude of the source produces a corresponding decrease in relative intensity of the higher order modes, so that for an intense explosion at high altitudes, the low-frequency gravity wave mode is dominant.

V.H. Weston, **"Gravity and Acoustical Waves,"** Can. J. Phys. 40, 446 (1962).

Abstract: The spectrum of the gravity and acoustical waves are discussed for two general types of models of the atmosphere. The main emphasis is placed upon the discrete set of modes which are important in the propagation of energy, long distances around the earth, from large explosions in the atmosphere.

F.B. Daniels, **"Generation of Infrasound by Ocean Waves,"** J. Acoust. Soc. Am. 34, 352 (1962).

Abstract: A summary is given of past observations of microbaroms, atmospheric pressure oscillations that have periods near 5 sec, and it is shown how the generation of these oscillations is explained by Nanda's theory of the origin of microseisims.

W.L. Webb, **"Detailed Acoustic Structure above the Tropopause,"** J. Appl. Meteorol. 1, 229 (1962). [June]

Abstract: The general features of atmospheric acoustic structure in the lower mesosphere have been known for several decades. Initial studies were accomplished by surface observations of anomalous propagation of pressure perturbations generated by explosions. Recently the expulsion of explosive grenades from rockets has served to reduce the spatial observation parameter from many miles to the order of 10,000 ft. The material considered here is based on a resolution of the order of 1000 ft over most of the region of interest. Data are presented on speed of sound structure evaluated from wind and temperature measurements obtained from meteorological rocket system observations. The environment is assumed to be a perfect gas of molecular composition the same as dry air at the earth's surface. The seasonal course of the general mesospheric sonic gradient is discussed, illustrating a midwinter maximum of some 6×10^{-3} per second and a mid-July minimum of 1×10^{-3} per second for a sound front approaching from the west in the horizontal planes in mid-latitudes. The same data in the sub-polar case presents a reduced maximum of some 4×10^{-3} per second and a shift in the date of minimum value to mid-June. Strength and frequency of occurrence of detailed features are presented, and extreme values of sonic gradient are presented as a function of height interval. The acoustic variability is considered from the latitude point of view, and the temperature and wind contributions to the sonic gradient are discussed.

V.H. Weston and D.B. van Hulsteyn, **"The Effect of Winds on the Gravity Wave,"** Can. J. Phys. 40, 797 (1962). [July]

Abstract: The effect of wind upon the gravity waves produced by large explosion is considered. The uniform horizontal wind is applied to the hydrodynamic equations; application of perturbation techniques results in an equation for excess pressure which involves the wind velocity. In the limiting case, as this velocity approaches zero, this equation becomes identical with the non-wind case. This equation is solved by numerical methods with appropriate boundary conditions for the particular model of the atmosphere considered. For a pulse traveling down wind, the effect is to increase the dispersion and the phase velocity in the gravity wave mode.

H. Wexler and W.A. Hass, **"Global Atmospheric Pressure Effects of the October 30, 1961, Explosion,"** J. Geophys. Res. 67, 3875 (1962). [September]

Abstract: The atmospheric pressure waves set off by the explosion of October 30, 1961, were traced over a large portion of the world, including the antipodes in the Antarctic, by means of analyses of available ordinary microbarograph records. The observed geographic variations in propagation speed and maximum amplitude are examined with the aid of air density and wind analyses. Comparison is made with the waves resulting from the great Siberian meteor of 1908 and the Krakatoa eruption of 1883.

F. Press and D. Harkrider, **"Propagation of Acoustic-Gravity Waves in the Atmosphere,"** J. Geophys. Res. 67, 3889 (1962).

Abstract: Homogeneous wave guide theory is used to derive dispersion curves, vertical pressure distributions, and synthetic barograms for atmospheric waves. A complicated mode structure is found involving both gravity and acoustic waves. Various models of the atmosphere are studied to explore seasonal and geographic effects on pulse propagation. The influence of different zones in the atmosphere on the character of the barograms is studied. It is found that the first arriving waves are controlled by properties of the lower atmospheric channel. Comparison of theoretical results and experimental data from large thermonuclear explosions is made in the time and frequency domains, and the following conclusions are reached: (1) The major features on barograms are due to dispersion; (2) superposition of several modes is needed to explain observed features; (3) scatter of data outside the range permitted by extreme atmospheric models shows the influence of winds for A_1; wind effects and higher modes are less important for A_2 waves. A discussion is included on atmospheric terminations and how these affect dispersion curves.

R.V. Jones and S.T. Forbes, **"Sub-Acoustic Waves from Recent Nuclear Explosions,"** Nature 196, 1170 (1962). [December]

Abstract: None.

S. Glasstone, **The Effects of Nuclear Weapons**, U.S. Government Printing Office, Washington, D.C. (1962).

W.L. Donn, D.M. Shaw and A.C. Hubbard, **"The Microbaragraphic Detection of Nuclear Explosions,"** IEEE Transactions on Nuclear Science p. 265, (1963). [January]

Abstract: In order to study the atmospheric pressure perturbations produced by the passages of gravity and acoustic-gravity waves through the atmosphere, a sensitive rate of change instrument (microbaragraph) has been developed at Lamont. Similar instruments of different design have also been in successful operation at several other institutions here and abroad. In general, this instrumentation has also proven capable of recording the pressure variations from nuclear explosions in the megaton range for distances which depend on the magnitude and elevation of the initial explosion.

W.L. Donn, R. L. Pfeffer and M. Ewing, **"Propagation of Air Waves from Nuclear Explosions,"** Science 139, 307 (1963). [January]

Abstract: Nuclear explosions provide data on the relation of air-wave propagation to atmospheric structure.

I. Tolstoy, **"The Theory of Waves in Stratified Fluids Including the Effects of Gravity and Rotation,"** Rev. Mod. Phys. 35, 207 (1963).

Abstract: None.

H. Wagner and U. Ericsson, **"Period and Amplitude in Atmospheric Gravity Waves from Nuclear Explosions,"** Nature 197, 994 (1983). [March]

Abstract: None.

R.H. Clarke, **"The effect of wind on the propagation rate of acoustic-gravity waves,"** Tellus 15, 287 (1963). [March]

Abstract: A method is described for deriving acoustic-gravity wave velocity in the presence of wind shear. It is used to calculate numerical weighting factors for a few special cases of two and three layer model atmospheres. These show that the wind velocity in a cold layer between two warm layers has a predominant positive influence on group velocity, and the wind at higher levels a negative influence, while phase velocity is quite differentially affected.

The theory is illustrated by world-wide data relating to the Russian megaton explosion of 30 October 1961, and a study of global winds at the time. It was found possible to account for world-wide variations in wave propagation rate largely by a simple regression on the sine of the explosion longitude, which made possible estimates of effective wind over various ray path lengths. This was found, on the global scale, to be the mean of the wind in the 9-16 km layer, that is, approximately the mean wind in the "sound channel". Negative weightings at higher levels predicted by the model appear to be incorrect, and due to its inadequacy. The data strongly suggest that the "level of effective mean wind" is approximately that of the tropopause in middle latitudes.

A.D. Pierce, **"Transient Sound Propagation in a Simple Model of a Triple-Layered Medium,"** Rand Corporation Technical Report RM-3478, April (1963). [April]

Abstract: A theoretical study has been made of the transient sound propagation from a point source in a triple-layered medium consisting of a homogeneous fluid layer sandwiched between two similar half spaces of the same density but of higher sound

speed. The source spectrum is such that a large number of normal modes are excited. Both source and receiver are assumed to be in the same half space. The general solution consists of a direct wave, a wave reflected from the near edge of the center layer, a lateral wave, and the normal and complex mode waves. At large distances r the normal mode waves dominate. It is found that one may relate frequency, phase velocity, group velocity, and excitation amplitudes parametrically, and, on the basis of this, the variation of the characteristics of the normal modes with mode number n is studied. Similar methods can be used to study the complex modes. Each normal mode is found to carry a limited band of frequencies - - the band width for higher order modes being approximately proportional to n^{-1}. Unless r is extremely large, the amplitudes of the Airy phases for the higher order modes will be negligible. On the basis of the study, one may give a qualitative description of the waveforms. One effect of placing source and receiver outside the center layer is to accentuate lower order modes and the lower frequency portion of the source spectrum.

A.D. Pierce, "**Propagation of Acoustic-Gravity Waves From a Small Source Above the Ground in an Isothermal Atmosphere,**" Rand Corporation Technical Report RM-3596, May (1963). [May]

Abstract: A theoretical discussion is presented of the influence of gravity on sound propagation from a small source in an isothermal atmosphere where ambient pressure and density decrease exponentially with height. A solution for the free-space case is derived which indicates that waves with angular frequency ω between $(\gamma-1)^{1/2}$ (g/c) and $(\gamma/2)$ g/c will not be propagated, while those with ω between 0 and $(\gamma-1)^{1/2}$(g/c) cos(θ) will not be propagated in a direction making an angle of θ with the vertical axis. A formal solution incorporating appropriate boundary conditions at the ground is derived and discussed. The field along the vertical line passing through the source is found explicitly. A consideration of the energy intensity shows that no energy is propagated within a cone above and below the source if $\omega < (\gamma-1)^{1/2}$(g/c). A calculation of the intensity for the case when $(\gamma-1)^{1/2}$(g/c) $< \omega < (\gamma/2)$ g/c indicates that the energy flowing from the source tends to concentrate in the lowest layers of the atmosphere. The field for large horizontal distances appears as a sum of a direct wave, a reflected wave, and a surface wave. Reflection coefficients are derived and the criteria for the surface wave to be dominant are discussed.

M. Diamond, "**Sound Channels in the Atmosphere,**" J. Geophys. Res. 68, 3459 (1963). [June]

Abstract: The mean temperature profile of the atmosphere indicates the probable existence of two horizontally distributed sound waveguides in the atmosphere. The lower one usually occurs between the surface and 50 km, and the upper between 50 and 110 km. Wind data above 30 km, which have become available recently through the use of meteorological rockets, have resulted in revised concepts of atmospheric circulation patterns for the northern hemisphere. Wind data obtained from these patterns have been combined with mean atmospheric temperature data to determine seasonal sonic patterns of the atmosphere waveguide that can exist between the surface and an altitude of about 50 km. These patterns indicate the general existence of a waveguide for sound having an eastward propagation component in winter a westward propagation component in summer. For other combinations of propagation directions and seasons, a waveguide does not usually exist between the surface and 50 km. The refraction of sound from upper altitudes to the surface

will generally occur only in winter at sites located to the east of the source and in summer at sites located to the west of the source.

T. Obayashi, **"Upper Atmospheric Disturbances Due to High Altitude Nuclear Explosions,"** Planet. Space Sci. 10, 47 (1963). [October]

Abstract: A review is given of the geophysical effects due to high altitude nuclear explosions. The sources of information are mainly from the high altitude detonations on August-September 1958 in the Pacific and in the South Atlantic. The nuclear tests at Novaya Zemlya, during October 1961, are included. Various upper atmospheric phenomena, such as ionospheric and geomagnetic storms, airglows, trapped particles and blast waves are identified as a consequence of nuclear explosions. An explanation of disturbance effects and the significance of controlled experiment in the upper atmosphere are discussed.

W.H. Campbell and J.M. Young, **"Auroral-Zone Observations of Infrasonic Pressure Waves Related to Ionospheric Disturbances and Geomagnetic Activity,"** J. Geophys. Res. 68, 5909 (1963). [November]

Abstract: Observations at Fort Yukon, Alaska, in August 1962 showed that most of the 10- to 110-sec-period infrasonic pressure waves during that period originated in auroral disturbances. Associated magnetic and cosmic noise absorption effects, together with determinations of the arrival direction of the pressure fluctuations, indicated an ionospheric source. We also studied a unique event, not of the auroral type, which appeared to give evidence that a large, primarily tropospheric pressure front could produce a disturbance in the ionosphere. Mechanisms for the two types of observations can be found in well-accepted, auroral-zone ionospheric processes.

A.D. Pierce, **"Propagation of Acoustic-Gravity Waves from a Small Source above the Ground in an Isothermal Atmosphere,"** J. Acoust. Soc. Am. 35, 1798 (1963). [November]

Abstract: A theoretical discussion is presented of the influence of gravity on sound propagation from a small source in an isothermal atmosphere where ambient pressure and density decrease exponentially with height. A solution for the free-space case is derived that indicates that waves with angular frequency ω between $(\gamma-1)^{1/2}g/c$ and $(\gamma/2)g/c$ will not be propagated, while those with ω between 0 and $(1-\gamma)^{1/2}(g/c)\cos\theta$ will not be propagated in a direction making an angle θ with the vertical axis. A formal solution incorporating appropriate boundary conditions at the ground is derived and discussed. The field along the vertical line passing through the source is found explicitly. A consideration of the energy intensity shows that no energy is propagated within a cone above and below the source if $\omega<(\gamma-1)^{1/2}(g/c)$. A calculation of the intensity for the case when $(\gamma-1)^{1/2}g/c<\omega<(\gamma/2)g/c$ indicates that the energy flowing from the source tends to concentrate in the lowest layers of the atmosphere. The field for large horizontal distances appears as a sum of direct wave, a reflected wave, and a surface wave. Reflection coefficients are derived, and the criteria for the surface wave to be dominant is discussed.

R.L. Pfeffer and J. Zarichny, **"Acoustic-Gravity Wave Propagation in an Atmosphere with Two Sound Channels,"** Geophys. Pura Appl. 55, 175 (1963).

Abstract: In order to interpret the observed features of pressure records produced by waves from large explosions in the earth's atmosphere, the writers have obtained numerical solutions of the homogeneous equations governing acoustic-gravity wave propagation in a stratified compressible fluid. Theoretical dispersion curves and variations of perturbation kinetic energy with altitude are presented for 11 normal modes. It is shown that the step-like character of the phase velocity curves in the velocity-period plane can be interpreted as being the result of interference between two families of normal modes - "quasi-horizontal modes" representing energy propagation in the lower atmosphere (below the ozonosphere) and "quasi-vertical modes" representing energy propagation in the upper atmosphere (above the ozonosphere). The theoretical prediction that several normal modes contribute to the observed barogram traces is verified by Fourier analysis of a number of wave records.

J.I.P. Jones, **"A band-pass filter technique for recording atmospheric turbulence,"** Brit. J. Appl. Phys. 14, 95 (1963).

Abstract: A description is given of multi-band electrical filters and associated circuits which can be used to simulate numerical methods of computing the magnitude of eddy velocity. The filters are supplied directly with the voltage from a wind sensor, and outputs from the filters are recorded as a mean deviations. These are then converted to standard deviations by multiplying by a "form factor". Evidence of the consistency of the form factor is presented. The equipment may also be used to obtain in "real time" a measure of the power or energy spectrum of wind gusts from a frequency of about 1 cycle per hour up to the cut-off frequency of the sensor.

D.B. van Hulsteyn, **"The Atmospheric Pressure Wave Generated by a Nuclear Explosion,"** University of Michigan (Radiation Laboratory) Technical Report No: 5033 IT; AFCRL-64 184, February (1964). NTIS Number AD-601 385.

Abstract: The problem of describing the pressure wave that an observer located on the ground will detect at a distance of a few thousand kilometers from a low altitude nuclear explosion is investigated. The result obtained entails the correlation of the theoretical values of the period and amplitude with those deter mined from microbarograph recordings. For the frequency spectrum considered, an isothermal atmospheric temperature model is sufficiently accurate and allows an analytic development of the Green's function. This Green's function makes it possible to express the frequency dependent pressure at an observer's position in terms of the pressure generated by a nuclear blast. It is convenient to treat this explosion by using a form of Huygen's principle, rather than a point source representation. This configuration permits the determination of the relationship between the energy of the explosion and the amplitude of the theoretical pressure pulse. The final step involves the performing of the inverse Fourier transform in order to determine the time variation of the pressure wave train. [Descriptors nuclear explosions; atmosphere, atmosphere; barometric pressure; mechanical waves; explosion effects; shock waves; frequency; recording systems; models (simulations); differential equations; green's function; integral transforms; numerical analysis.]

Bhartendu and B.W. Currie, **"Atmospheric Waves from U.S.S.R. Nuclear Test Explosions in 1962,"** Can. J. of Phys. 42, 632 (1964). [April]

Abstract: Photographic reproductions of the records of the A_1 wave systems at Saskatoon (52.1^o N., 106.6^o W.) from five nuclear test explosions in Novaya Zemlya during the summer of 1962 are given. Notable differences exist between some of the records. These may be due to differences in the heights of the explosions. Dispersion curves of group velocity against period are shown. Waves ranged in period from 6.0 to 0.8 minutes; group velocities from 275 to 313 m/sec.

J.W. Reed, **"Project Danny Boy, Nevada Test Site. Long-Range Air-Blast Measurements and Interpretations,"** Sandia National Laboratories Technical Report No: POR-1809-1-SAN, May 15, (1964). NTIS Number ADA279 735/5/XAB.

Abstract: Low-pressure air blast was measured for Project Danny Boy out to distances of 240 kilometers in order, primarily, to determine the attenuation caused by the hard rock environment of the shot and to compare results from both nuclear and HE shots in other media. Nine microbarograph stations were operated. Communications problems and strong local winds reduced the number of signal correlation points. Air-blast pressures, both close-in and far-out, were smaller than were expected, based on past experience with underground HE shots. Distant off-site recordings indicated that blast pressure amplitudes from the Danny Boy shot averaged only 14 percent as large as would have been received from a shot having the same nuclear yield, free-air-burst. [Descriptors: nuclear explosion testing; blast loads; underground explosions; low pressure; aluminum; surface burst; long range(distance); blast waves; air masses; ground shock; yield (nuclear explosions). Identifiers: Project Danny Boy; NTISDODXA.]

J.L. Collins, W.C. Richie and G.E. English, **"Solion Infrasonic Microphone,"** J. Acoust. Soc. Am. 36, 1283 (1964). [July]

Abstract: The solion infrasonic microphone is an electrochemical pressure transducer designed for the measurement of atmospheric-pressure variations. An over-all transducer frequency response from 0.003-50 cps and a dynamic range from 0.1-1000 dyn/cm^2 has been obtained with the design described. Stability, sensitivity, low power consumption, and remote-operation capability are the inherent features of this new acoustic tool. Descriptions of the solion transducer, the infrasonic microphone, and the over-all response of the system are presented.

N. Murayama, **"Analysis of Atmospheric Pressure Waves Caused by Large-Scale Nuclear Explosions: 1961-1962,"** Aerospace Technology Division (Library of Congress) Technical Report No: ATD-U-64-73 [Translation from Journal of Meteorological Research, 15(5) pp 1-14; 29-33 (1963)], July 17 (1964). NTIS Number AD-459 622/7.

Abstract: Recent recordings of pressure waves caused by nuclear explosions were of good quality resulting from improvements in the microbarograph and greater amplification of the recordings. In 1961 to 1962 clear microbarograph recordings were taken mainly of several large-scale nuclear tests at Novaya Zemlya. It was possible to investigate in detail the propagation distances of pressure waves. On 30 October 1961 the waves from a 55 to 60 megaton (Mton) blast at Novaya Zemlya had dispersed on a global scale and were abundantly reported. Comparisons of theoretical characteristics of pressure waves (from the atmospheric models Oyamamoto, et al) with the measurements were made and

analyzed with the help of even newer models. [Descriptors: nuclear explosions; microbarometric waves; propagation; measurement; atmospheres; Japan; wind; velocity; wave propagation; shock waves; USSR. Identifiers: Novaya Zemlya; NTISDODXD.]

A.D. Pierce, "**Propagation of Acoustic-Gravity Waves in a Temperature- and Wind-Stratified Atmosphere,** AFCRL (Air Force Cambridge Research Laboratories) Technical Report: AFCRL-64-711, August 28, (1964). [August]

Abstract: A theory is presented which permits the study of the effects of horizontal winds on the dispersion and amplitudes of acoustic-gravity waves in the atmosphere. It is shown that the effective horizontal group velocity for a given frequency in a given normal mode depends on the direction of propagation as well as on frequency and that it is not necessarily in the same direction as the horizontal wave number vector. A number of useful integral theorems are derived from a variational principle and one is subsequently applied to the development of a perturbation method for the computation of wind effects on dispersion. Application of the method to a realistic example indicates that winds can appreciably alter the dispersion of the normal modes and that they should be considered in any quantitative interpretation of experimental microbarograms.

W.L. Donn and E.S. Posmentier, "**Ground-Coupled Air Wave from the Great Alskan Earthquake,**" J. Geophys. Res. 69, 5357 (1964). [December]

Abstract: Micropressure fluctuations occurring at the same time as the arrival of seismic waves were recorded at many localities following the Alaskan earthquake of March 27, 1964. It is shown that at Palisades, New York, Berkeley, California, and Honolulu, Hawaii, the pressure waves were produced by vertical ground motion associated with local Rayleigh waves arriving from the epicenter. Group velocity dispersion curves typical of Rayleigh wave modes from the first two localities. Both oceanic and continental Rayleigh modes are indicated for Berkeley. A later train of waves arrived at a time appropriate for acoustic travel through the atmosphere directly from the epicenter. Although reminiscent of acoustic waves from large explosions, their generation over the large region of vertical ground displacement complicates their study.

D.G. Harkrider, "**Theoretical and Observed Acoustic-Gravity Waves from Explosive Sources in the Atmosphere,**" J. Geophys. Res. 69, 5295 (1964). [December]

Abstract: A matrix formulation is used to derive the pressure variation for acoustic-gravity waves from an explosive source in an atmosphere modeled by a large number of isothermal layers. Comparison of theoretical and observed barograms from large thermonuclear explosions leads to the following conclusions: (1) The major features on the barogram can be explained by the superposition of four modes, (2) different parts of the vertical temperature structure of the atmosphere control the relative excitation of these modes, (3) a scaled point source is sufficient to model thermonuclear explosions, (4) the observed shift in dominance of certain frequencies with yield and altitude can be explained by means of the empirical scaling laws derived from the direct wave near the explosion and (5) out to 50^{o} from the source, the observed variation in amplitude with distance can be accounted for by geometrical spreading over a spherical surface.

D.B. van Hulsteyn, **"The Atmospheric Pressure Wave Generated by a Nuclear Explosion. Part 1,"** J. Geophys. Res. 70, 257 (1965). [January]

Abstract: The problem of describing the pressure wave detected by an observer on the ground a few thousand kilometers from a low-altitude nuclear explosion is formulated. To avoid numerical complications, the atmosphere is assumed to have an isothermal temperature distribution. With this simplification a Green's function for the problem is developed as an expansion in Legendre polynomials. This representation yields a time-dependent pressure function which satisfies the condition of causality but which converges far too slowly to be useful. An alternative scheme, which is entirely equivalent, makes use of a Watson transformation and requires the determination of the set of Regge poles. The behavior of the complete Green's function is then shown to be dominated by the so-called gravity wave mode, and the form of this approximate solution is developed.

D.B. van Hulsteyn, **"The Atmospheric Pressure Wave Generated by a Nuclear Explosion. Part 2,"** J. Geophys. Res. 70, 271 (1965). [January]

Abstract: The Green's function of part 1 makes it possible to determine the time-dependent pressure function at the observer's position in terms of the pressure generated by a nuclear explosion. It is convenient to treat the blast by using a surface, rather than a point source representation. This configuration permits the determination of the relationship between the energy of the explosion and the amplitude of the theoretical pressure pulse. The final step involves the performing of an inverse transformation to determine the time variation of the pressure wave train.

A.D. Pierce, **"Propagation of Acoustic-Gravity Waves in a Temperature- and Wind-Stratified Atmosphere,"** J. Acoust. Soc. Am. 37, 218 (1965). [February]

Abstract: A theory is presented that permits the study of the effects of horizontal winds on the dispersion and amplitudes of acoustic-gravity waves in the atmosphere. It is shown that the effective horizontal group velocity for a given frequency in a given normal mode depends on direction of propagation as well as on frequency and that it is not necessarily in the same direction as the horizontal-wavenumber vector. A number of useful integral theorems are derived from a variational principle and one is subsequently applied to the development of perturbation method for the computation of wind effects on dispersion of the normal modes and that they should be considered in any quantitative interpretation of experimental microbarograms.

A. Wiin-Nielsen, **"On the propagation of gravity waves in a hydrostatic, compressible fluid with vertical wind shear,"** Tellus 17, 306 (1965).

Abstract: The speed of propagation of the vertical modes of gravity waves is found in a non-rotating hydrostatic and compressible fluid with a vertical variation of mean temperature and wind. The analysis is based on a set of linearized equations, and it is assumed that the basic flow as well as the perturbations are hydrostatic. We are therefore concerned with one of the possible wave-type solutions to the primitive equations as they are being used in studies of the general circulation of the atmosphere and in other dynamical studies of the atmosphere.

In the case of a constant static stability it is found that the speed of propagation of internal gravity waves is determined by the Richardson number. If the (positive) Richardson number is smaller than 1/4, the waves will move with a speed determined by

the basic flow at the bottom of the fluid. For Richardson numbers larger than 1/4 several vertical modes moving with different speed will exist. The speed of propagation is evaluated as a function of the vertical wave number and the vertical wind shear for given values of the static stability.

The speed of the external gravity waves is evaluated numerically. It is found that the main difference is the existence of a mode which has a numerically large phase speed and which has a maximum amplitude of the vertical velocity at the boundary. The modes of the internal waves move with almost the same speed as before. The amplitudes of vertical velocity and geopotential are computed as functions of pressure for the internal and external gravity waves.

The results of this study which apply to a hydrostatic and compressible atmosphere are compared in the last section with certain general results, obtained in earlier investigations, for a non-hydrostatic, incompressible fluid. A significant condition for stability has been found and an upper and lower limit on the magnitude of the complex root has been determined.

A.F. Wickersham, Jr., "**Comparison of Velocity Distributions for Acoustic-Gravity Waves and Traveling Ionospheric Disturbances,**" J. Geophys. Res. 70, 4875, (1965). [October 1, 1965]

Abstract: Using machine-computed dispersion curves for ducted, atmospheric acoustic-gravity waves, reported earlier by Pfeffer and Zarichny, we have calculated the acoustic-gravity velocity distributions that would be detectable by high-frequency radio experiments. We compare the theoretical distributions with those observed by Tveten and Munro, and the motion in sporadic E observed by Dueno. Except for part of Munro's data, we find statistically significant agreement between theory and experiment.

W.C. Meecham, "**Simplified Normal Mode Treatment of Long-Period Acoustic-Gravity Waves in the Atmosphere,**" Proc. IEEE 53, 2079 (1965). [December]

Abstract: This paper deals primarily with the effects of geometric dispersion on low-frequency mechanical waves generated by nuclear explosions. This dispersion is the result of the stratification of the atmosphere (to be distinguished from dispersion due to changes in physical characteristics due to changing frequency). It is found that the pressure signal can be divided naturally into an early-arriving acoustic-gravity wave portion (treated in this report) and a later - by about five percent of the travel time-acoustic portion.

In general, both portions of the signal are inversely proportional to the range (geometric spreading included), although, at very great ranges, portions of the gravity wave fall off faster by $r^{1/6}$; the effect of dispersion is to reduce the signal by $r^{-1/2}$. Most of the signal is composed of many propagating modes which, at a given time and range, will each demonstrate a characteristic frequency. A simplified treatment of this complicated modal picture is presented here. It is argued that a ray treatment for the higher-frequency portion is appropriate. It is shown that the frequency of the long-period signal increases with time. So long as the frequency of the received signal is less that the characteristic frequency of the initiating explosive impulse, it is found that the signal has a universal form for the fundamental mode. Such characteristics as yield, range, and phase velocity merely change the scaling of the signal. It is concluded that attenuation is probably not important for the low-frequency signals (below one c/s) usually observed.

A.D. Pierce, "**A Method for the Computation of Normal Mode Dispersion Curves of Atmospheric Gravity Waves in Windy Atmospheres,**" AFCRL (Air Force Cambridge Research Laboratories) Technical Report AFCRL-66-44, January (1966). [January] NTIS Number 628942.

Abstract: The multilayer approximation previously used to study propagation in wind-free atmospheres is extended to include winds. Two generalized acoustic potentials are defined. These are continuous even at horizontal discontinuities in wind velocity or sound speed, and the residual equations which these quantities satisfy are derived. Two dispersion functions are defined. Their roots give the phase velocity magnitude and phase velocity direction for normal mode waves propagating with given frequency and given group velocity direction. The multilayer approximation is introduced for computing these dispersion functions by approximating continuously stratified atmospheres with models consisting of a finite number of layers, each with constant wind velocity and sound speed. Numerical methods for finding the roots of the dispersion function are discussed. The theory is then applied to an example of a multilayer atmosphere.

A.D. Pierce, "**Justification of the Use of Multiple Isothermal Layers as an Approximation to the Real Atmosphere for Acoustic-Gravity Wave Propagation,**" Radio Science 1, 265 (1966). [March]

Abstract: The validity of the multilayer approximation for the study of acoustic-gravity wave propagation in the atmosphere is demonstrated in the limit of small layer thicknesses. The principal basis of the justification is the existence of two coupled first-order differential equations with coefficients, which do not depend explicitly on derivatives of the sound speed with respect to height.

J.W. Reed, "**Amplitude Variability of Explosion Waves at Long Ranges,**" J. Acoust. Soc. Am. 39, 980 (1966).

Abstract: Microbarograms, made at long range from 10^6-g high explosives fired at few-minute intervals, were compared to show atmospheric propagation variability. Records made at 40-250-km ranges gave amplitude repeatability with a logarithmic-normal standard deviation of 0.49.

G.G. Bowman and K.L. Shrestha, "**Ionospheric Storms and Small Pressure Fluctuations at Ground Level,**" Nature 210, 1032 (1966). [June]

Abstract: None.

L.J. Vortman, "**Air-Blast Suppression as a Function of Explosive-Charge Burial Depth,**" J. Acoust. Soc. Am. 40, 229 (1966).

Abstract: The blast wave from buried explosions consists primarily of a pulse induced by the ground shock followed by another pulse when the explosive gases are vented to the atmosphere. The latter pulse provides the dominant contribution for the shallower burial depths. Air-blast measurements made along the ground surface for 46 chemical explosive and 7 nuclear explosive detonations have shown the peak overpressure of the ground-shock-induced pulse to be about the same for chemical and nuclear explosions in basalt rock as for chemical explosions in alluvial soil. The ground-shock-induced pulse has not

been observed for nuclear explosions in soil. The peak overpressure from venting gases is about equal for chemical explosives in basalt rock and alluvial soil. Peak overpressures are lower for nuclear explosions in rock, presumably because less gas is formed and because the pulse from venting gas coincides with the negative phase following the ground-shock-induced pulse, thus reducing overpressure amplitude. Measurements have been made over a sufficiently large range of burial depths that a pattern of air-blast suppression with charge burial can be presented.

A.D. Pierce and S.C. Coroniti, **"A Mechanism for the Generation of Acoustic-Gravity Waves During Thunderstorm Formation,"** Nature 210, 1209 (1966). [June]

Abstract: None.

Bhartendu and R. McCrory, **"Atmospheric Pressure Wave from an Explosion,"** Nature 211, 396 (1966). [July].

Abstract: None. Paper presents microbarograph recordings for chemical explosions.

J.E. Midgley and H.B. Liemohn, **"Gravity Waves in a Realistic Atmosphere,"** J. Geophys. Res. 71, 3729 (1966). [August 1]

Abstract: The atmospheric winds at ionospheric altitudes exhibit irregular short-period wavelike components that have been observed through their distortion of meteor ionization trails and rocket vapor trails. An explanation for these components was proposed by Hines in his theory for internal atmospheric gravity waves in an isothermal medium. The isothermal theory is refined here to unify the treatment of acoustic, gravity, and evanescent waves in a gravitational atmosphere and to explain the physical processes behind these atmospheric motions. A technique is developed for the solution of the complete hydrodynamic equations the avoids the fatal difficulties normally caused by 'viscous waves' and their thermal counterpart. This technique is used to solve the general problem of gravity wave propagation in a realistic atmosphere for a wide range of wave parameters. The height of maximum wind amplitude and the fraction of reflected energy have been plotted from the results of these calculations. These maxima are also compared with simpler analytic approximations and experimental observations.

A.F. Wickersham, Jr., **"Identification of Acoustic-Gravity Wave Modes from Ionospheric Range-Time Observations,"** J. Geophys. Res. 71, 4551 (1966). [October]

Abstract: The nuclear detonation at Novaya Zemlya on October 30, 1961, produced a traveling disturbance in the ionosphere that was recorded by ionospheric sounding stations on the European continent. A compilation of the times of occurrence of maximum in perturbations at various stations permits a determination of the propagation speeds of various components of the disturbance. By comparing such data with theory, we find that the disturbances were the acoustic modes, the fundamental, and the second to fifth gravity-wave modes of fully ducted, acoustic gravity waves.

W.C. Meecham, **"Short-Period Propagation of Infrasonic Waves from Nuclear Explosions,"** RAND Corporation (Santa Monica, CA) Technical Report No: RM-5103-ARPA, October (1966). NTIS Number AD-643 536.

Abstract: A possible explanation is given for the great time duration of intermediate-period (about one minute) and short-period (less than one minute) acoustic-gravity waves received from nuclear explosions. It is suggested that the signal delay for intermediate periods may be due to refraction from large-scale weather fronts, and that the signal delay for short periods may be caused by commonly occurring wind ducts. [Descriptors: nuclear explosions; sound signals; sound signals; propagation; time; refraction; climatology. Identifiers: infrasound.]

W.J. Breitling, R.A. Kuperman and G.J. Gassmann **"Traveling Ionospheric Disturbances Associated with Nuclear Detonations,"** J. Geophys. Res. 72, 307 (1967). [January]

Abstract: The analysis of ionospheric data taken from 54 ionosonde observatories throughout the world indicates the presence of several traveling ionospheric disturbances originating from the five high-altitude nuclear tests conducted over Johnston Island in 1962. These disturbances were propagated over large distances and were observed as changes in the F_2-layer critical frequency. They are interpreted as a series of waves that are propagated at various velocities. Travel time curves are presented indicating dispersion and a range of velocities from 50-900 /sec.

C.O. Hines and C.A. Reddy, **"On the Propagation of Atmospheric Gravity Waves through Regions of Wind Shear,"** J. Geophys. Res. 72, 1015 (1967). [February]

Abstract: The propagation of atmospheric gravity waves to ionospheric heights from lower regions is complicated by the presence of background wind shears, which can act to remove a portion of any incident wave spectrum. This paper is designed to evaluate the possible importance of such a removal process. The general problem of acoustic-gravity waves, propagating through regions of vertically varying background winds and temperatures, is investigated first. A multilayer approximation is adopted, and methods for evaluating the transmission of energy are established. Certain fundamental problems in the propagation of hydrodynamic energy are raised, but not pursued in depth. The importance of singular levels in the wind profile is reconfirmed, through with an emphasis on absorption rather than reflection at such levels. An unanticipated importance of temperature gradients is clarified in the course of the analysis. Calculated transmission coefficients are presented for three assumed atmospheric wind profiles, with and without temperature structure. The results indicate that the processes considered here will not severely attenuate a broad incident wave spectrum in the course of its upward passage through the mesosphere, though strong attenuation, particularly of modes with horizontal phase speeds ≤ 50 m/sec, must be expected low in the thermosphere. Even when the over-all attenuation is low, substantial directional filtering can occur such that the wave spectrum in ionosphere regions may exhibit marked azimuthal variations in response to the wind structure at underlying levels. It is suggested that this directional filtering can be a major cause of the seasonal and diurnal variations that occur in measured ionospheric drifts.

W.L. Donn and D.M. Shaw, "**Exploring the Atmosphere with Nuclear Explosions,**" Reviews of Geophysics 5, 53 (1967). [February]

Abstract: Pressure waves from large nuclear explosions have been recorded at many stations over the earth by instruments installed by the Lamont Geological Observatory. The propagation of these waves is controlled primarily by gravity and the acoustic properties of the atmosphere in a manner that produces group velocity dispersion of the acoustic gravity modes making up the signal. The nature of the wave dispersion depends on both the thermal and the wind stratification of the atmosphere. The casual relationships have been studied both experimentally and theoretically. To provide more data for air-wave investigations, the 208 Lamont records made at 15 stations from 45 nuclear explosions are presented here together with related data on source, times and distances.

R. V. Row, "**Acoustic-Gravity Waves in the Upper Atmosphere Due to a Nuclear Detonation and an Earthquake,**" J. Geophys. Res. 72, 1599 (1967). [March]

Abstract: The large nuclear detonation low in the atmosphere over Novaya Zemlya on October 30, 1961, caused a traveling ionospheric disturbance observed widely on high-frequency radio sounders. A similar but much weaker disturbance was noted after the great Alaskan earthquake of March 1964. Both disturbances exhibit an abrupt onset traveling at speeds appropriate to sound waves above 100-km altitude and an oscillatory long-period tail. Both these properties are shown to be a characteristic of the propagation of a disturbance from a localized impulse source in an unbounded dissipationless, planar, nonrotating, gravitationally stratified isothermal neutral atmosphere. The theory for pulse propagation in such an atmosphere is developed, including a simple closed-form approximation appropriate to long-period components of the motion (i.e., periods greater than the Brunt period), which exhibit the major features of the observations.

C.O. Hines, "**On the Nature of Traveling Ionospheric Disturbances Launched by Low-Altitude Nuclear Explosions,**" J. Geophys. Res. 72, 1877 (1967). [April]

Abstract: The nuclear explosion of October 30, 1961, over Novaya Zemlya, resulted in major perturbations of the F-Layer critical frequency, even at very great ranges from the explosion site. These perturbations have been interpreted in terms of long-period gravity waves, and more recently in terms of shorter-period acoustic-gravity waves. It is shown here that the new interpretation is unsatisfactory, while the old is perfectly consistent with the observations if allowance is made for the obliquity of energy propagation. The results have some bearing on natural traveling ionospheric disturbances as well.

C.G. Justus, "**The Spectrum and Scales of Upper Atmospheric Turbulence,**" J. Geophys. Res. 72, 1933 (1967). [April]

Abstract: Turbulent winds determined by photographic tracking of chemical release clouds are used to determine the turbulence structure function in the 90-110 km region. The observations indicate that the turbulence structure function is approximately isotropic with a large scale of about 5 km. The turbulence structure function is found to vary, as $r^{2/3}$ in the 1- to 5-km scale range. However, there is insufficient observational data and theoretical background to determine if this is a true intertial scale range or is a 'pseudo-inertial' region in which wind shear production and buoyancy loss are approximately balanced, leading to

no net loss from the spectrum. Structure functions of the total wind profile are also discussed and related to a possible form for the gravity wave spectrum.

W.L. Donn and E.S. Posmentier, **"Infrasonic Waves from the Marine Storm of April 7, 1966,"** J. Geophys. Res. 72, 2053 (1967). [April]

Abstract: Nearly sinusoidal microoscillations of air pressure of the order of 1 to 10 microbars (dynes/cm^2), which have been recorded on a Lamont tripartite array of line microphones, have been identified as infrasonic waves arising from an intense atmospheric low pressure system off Newfoundland. Although the nearly sinusoidal pressure variations show good coherence among the stations, there is enough wave breakdown among the stations to suggest interference from a widespread source. Other factors indicate this source to be ocean waves. It is concluded that the spectral character of both microbarom amplitude variations depend also on atmospheric conditions along the path.

U. Fehr, **"Measurements of Infrasound from Artificial and Natural Sources,"** J. Geophys. Res. 72, 2403 (1967). [May]

Abstract: A quadrangle array of infrasonic detectors to monitor rocket engine noise during flight through the atmosphere and lower ionosphere monitored the atmospheric background noise, as well, for a period of two hours around the launching time. Data acquired gave a description of the rocket engine noise in the frequency range of 20-0.05 cps. It is proven that signals from rockets igniting in the upper atmosphere and ionosphere travel long distances and can be detected by the ground sensors. The atmospheric background noise consists of a great variety of sources, some of which are pressure fluctuations traveling with low velocity of approximately 5-50 m/sec. Other sources are infrasonic in nature. The data were analyzed by means of analog and mathematical bandwidth filters and power and cross spectra methods. Some studies were made by utilizing calculation of travel time and ray-tracing techniques.

G.M. Daniels, **"Acoustic-Gravity Waves in Model Thermospheres,"** J. Geophys. Res. 72, 2419 (1967). [May]

Abstract: The acoustic-gravity wave equation is solved analytically for an atmosphere whose sound speed squared profile is of the form: $c^2(z) = A + Be^{5z}$. Application of the solution is made to the study of ducted waves in the thermosphere. The results in the long-period range, where the model should be realistic, compare favorably to observational data.

J. Viecelli, **"Atmospheric Refraction and Focus of Blast Waves,"** J. Geophys. Res. 72, 2469 (1967). [May]

Abstract: An integral solution to the wave equation in an inhomogeneous half-space is used to derive the time-dependent pressure variation in the neighborhood of a first focus. Theoretically calculated signals are compared with barograph records. Conclusions are: (1) The curve of maximum peak-to-peak pressure versus distance is bell shaped; the dome of the bell is located on the far side of the caustic. (2) Width of the bell is proportional to the 2/9 power of the energy released to the atmosphere. (3) Height of the dome is proportional to the 5/18 power of the energy release. (4) The signal wave shape is quite sensitive to position near the caustic: on the near side the signal consists of a single long smooth wave;

at the caustic the wave steepens into a spike followed by a dip; on the far side the signal divides into two separate portions, a relatively smooth wave followed by a period of science followed by a wave containing a spike. (5) Close correlation between theoretical and observed signals is unlikely for a single event at a single recording station. (6) The theoretical focus is narrower and more intense than that experimentally observed.

W.C. Richie and D.R. Cook, "**Characteristics of Long-Range Atmospheric Infrasonic Propagation,**" J. Acoust. Soc. Am. 41, 1377 (1967). [May]

Abstract: A surface explosion of 500 tons of TNT at the Suffield Experimental Station Alberta, Canada, was monitored with a solion infrasonic microphone at a horizontal distance of 299 km to the southwest. The frequency response of the infrasonic microphone extended from 0.01-50 Hz. Statistical analysis using the power spectra and deterministic analysis using the amplitude spectra show a primary signal component at 0.26 Hz. Additional examination of the autocorrelation function and the power spectra indicates that atmospheric turbulence modulated the infrasonic wave as it propagated to the monitoring site. It is also suggested that this modulation could provide a measure of the atmospheric turbulence along the propagation path.

U. Fehr, "**Instrumentational Role in the Observation of Geoacoustical Phenomena from Artificial Sources,**" J. Acoust. Soc. Am. 42, 991 (1967). [June]

Abstract: Many physical principles have been applied to transform atmospheric pressure fluctuations of 1 sec and longer into electrical signals for the purpose of monitoring infrasonic signals. A survey of some infrasonic sensors is taken, with calibration and testing of several sensors at the UCLA calibration facility. An attempt was made to define the capabilities of each available sensor. Several experiments are described, which include the monitoring of static and dynamic firing of rockets, as well as the monitoring of explosions. The difficulties in interpretation of data are explained in relation to various instruments, taking into account wind effects, ground vibrations (observed by magnetometers), natural pressure fluctuations, and other phenomena producing noise at the frequency range of interest.

R.V. Jones, "**Microbarograph Record of Waves from the Chinese Thermonuclear Explosion on June 17, 1967,**" Nature 215, 672 (1967). [August]

R.F. MacKINNON, "**The effects of winds on acoustic-gravity waves from explosions in the atmosphere,**" Quart. J. Roy. Meteor. Soc. 93, 436 (1967).

Abstract: Pressure fluctuations due to an explosive point-source in an atmosphere containing steady winds may be described in terms of a fundamental mode of long period followed by modes of the acoustic and gravity type, with relative amplitudes, group speeds and periods dependent upon winds. Far-field ground-pressure contributions of various modes are presented for a particular model atmosphere. Inverse dispersion and the Airy phase are found to be important features of the dispersion. A study is made of barograms in the light of new results obtained. Some previously unexplained features of barograms are seen to be attributable to winds.

A.D. Pierce, **"The Multilayer Approximation for Infrasonic Wave Propagation in a Temperature- and Wind-Stratified Atmosphere,"** J. Comp. Physics 1, 343 (1967).

Abstract: The multilayer approximation previously used to study propagation in wind-free atmospheres is extended to include winds. Two generalized acoustic potentials are defined which are continuous even at horizontal discontinuities in wind velocity or sound speed and the residual equations which these quantities satisfy are derived. Two dispersion functions are defined whose roots give the phase-velocity magnitude and phase-velocity direction for normal-mode waves propagating with given frequency and given group-velocity direction. The multilayer approximation is introduced for computing these dispersion functions by approximating continuously stratified atmospheres with models consisting of a finite number of layers, each with constant wind velocity and sound speed. Numerical methods for finding the roots of the dispersion function are discussed. The theory is then applied to an example of a multi-layered atmosphere and curves, for several horizontal group-velocity directions, of phase-velocity, group-velocity, and phase-velocity direction versus frequency are tabulated for several normal modes.

I. Tolstoy, **"Long-Period Gravity Waves in the Atmosphere,"** J. Geophys. Res. 72, 4605 (1967).

Abstract: In stratified fluids in equilibrium in a gravity field, wave trains of sufficiently long periods effectively correspond to incompressible motion, and, for this part of the spectrum, it is possible to represent the atmosphere by one or two incompressible layers of given Vaisala frequency. The upper surface of this model can be treated as a free boundary at a height $z = h$ several hundred kilometers above the earth's surface. This is assumed because (1) as $z - h$, the mean free path l of the molecules becomes of the order of the wavelength λ (above this height one is dealing with a vacuum) and (2) the boundary layer thickness between this surface and the lower region in which the continuous equations are valid is small compared with λ (λ of the order of several hundred kilometers or more). The averaged kinematic viscosity over the whole atmosphere is not prohibitive for these very long periods (20 min to several hours). The interesting feature of this model is that it allows the propagation o surface gravity modes at wavelengths exceeding a few hundred kilometers and velocities in the range of 400-800 m/s.

E.S. Posmentier, **"A Theory of Microbaroms,"** Geophys. J. R. astr. Soc. 13, 487 (1967).

Abstract: A theory analogous to the Longuet-Higgins theory on the generation of microseisms explains the generation of microbaroms by standing water waves associated with marine storms. The spectral characteristics and the amplitude order-of-magnitude of microbaroms that are predicted by this theory agree well with observations. The theory is based on the oscillations of the centre of gravity of the air above the ocean surface on which the standing waves appear (or at the water below, to explain microseisms). These oscillations are of twice the ocean wave frequency and thereby explain the observed frequency-doubling common to both microbaroms and microseisms. The theory is expanded by statistical methods to predict the microbarom-generating effect of more realistic ocean waves, whose phases vary randomly over the ocean surface. In addition, the effect of the widespread source on microbarom coherence and resolvability at the receiving array is discussed.

N.Z. Pinus, E.R. Reiter, G.N. Shur and N.K. Vinnichenko, **"Power spectra of turbulence in the free atmosphere,"** Tellus 19, 206 (1967).

Abstract: Presently known data on the spectrum distribution of turbulence energy in the free atmosphere near jet-stream level are combined from various Russian, Australian and American sources. A comparison is made between these data. Special attention is given to the phenomenon of clear-air-turbulence.

A.A. Few, A.J. Dessler, D.J. Latham and M. Brook, **"A Dominant 200-Hertz Peak in the Acoustic Spectrum of Thunder,"** J. Geophys. Res. 72, 6149 (1967). [December]

Abstract: The dominant peak in the acoustic spectrum of thunder was determined from two independent studies in which two separate techniques were used. The dominant frequency determined by counting zero crossings in a unit time interval on a pressure versus time record peaked in the range 180 Hz to 260 Hz. An average power spectrum of twenty-three thunder records showed a broad maximum near 200 Hz. In neither study was there any evidence of a dominant infrasonic component (<20 Hz), although the equipment used was capable of measuring frequencies as low as 0.1 Hz. A theoretical analysis is presented to show that the observed peak occurs in a frequency range expected to be radiated from a cylindrical source with an energy input per unit length equal to that produced by a lightning flash.

R.H. Grover, **"Research Notes: A Note on Infrasonics at U.K.A.E.A. Blacknest,"** Geophys. J.R. astr. Soc. 16, 311 (1968).

Abstract: An array of microbarographs has been established at Blacknest to provide an improved capability in recording and analysis of infrasonic waves of small amplitude. An adaptation of an array processing method developed originally for seismic signals is described and two examples of applying this method to small infrasonic signals are given.

E.L. Hill and J.D. Robb, **"Pressure Pulse from a Lightning Stroke,"** J. Geophys. Res. 73, 1883 (1968). [March]

Abstract: Measurements of pressure pulses from triggered lightning strokes show that they are not the result of strong mechanical shock waves of the type postulated by Abramson et al. as the explanation of channel growth in spark breakdown. Physical arguments, which are applicable also to natural lightning strokes, indicate that the rate of thermal heating in the channel is too slow to allow the development of the required strong ionizing shock front.

Bhartendu, **"A study of atmospheric pressure variations from lightning discharges,"** Can. J. Phys. 46, 269 (1968).

Abstract: Observations were made at Saskatoon, Canada, during 1962 and 1963 on the pressure variations associated with thunder.

Close flashes are followed by a loud burst of sound, distant flashes by a rumble which develops into a loud burst, and very distant flashes by rumbles only. Infrasonic spectral-density studies show that maxima occur in the frequency range 0.75-6 c.p.s., the most intense occurring in the range 1-3 c.p.s. Three distinct types of spectra were

observed-type A with only one intense primary maximum, type B with two or more primary maxima, and type C with no intense primary maxima. The audiofrequency maxima were observed mostly in the frequency ranges 22-28, 52-56, and 66-78 c.p.s. Maxima also occurred in the ranges 34-40, 88-90, 122, and 202-204 c.p.s. The initial impulse from the first peal of thunder was always a compression and for successive peals was mostly a compression. Histograms of the duration of thunder suggested that the most common time range is from 5 to 20 seconds.

Directions of arrival showed that peals of thunder arrived directly from the flash and successive peals from different parts of the same flash (only very rarely from different strokes). The thunder claps which often contribute to the rumbles in the last phases of thunder arrived either from higher or more distant parts of the flash or from a reflection.

A.H. Benade, **"On the Propagation of Sound Waves in a Cylindrical Conduit,"** J. Acoust. Soc. Am. 77, 616 (1968). [April]

Abstract: The series impedance and shunt admittance of an acoustic line is calculated from the linearized acoustic equations. Exact and limiting formulas for small and large tubes are provided for R, L, G, C, the real and imaginary parts of the characteristic impedance Z_0, as well as the phase velocity v and attenuation constant α. All results are presented in convenient form for quick computation on the basis of tables and graphs. A self-consistent set of molecular data is presented. Accuracies of formulas and of the data are discussed in detail.

D.L. Jones, G.G. Goyer and M.N. Plooster, **"Shock Wave from a Lightning Discharge,"** J. Geophys. Res. 73, 3121 (1968). [May]

Abstract: A theoretical model of the shock wave from a lightning discharge ranging from the strong blast wave region out to the acoustic limit is given for the first time. The trajectory and overpressure of the strong shock wave are described by the well-known equations for cylindrical blast waves. In the intermediate shock strength region ($1.1 < M < 3.3$), the shock trajectory is given by the 'correct limit' equation of Vlases and Jones. We derive an additional 'correct limit' equation for overpressure that is valid out to the acoustic limit. The correct limit equations predict a much slower decay of the intermediate shock wave; thus, the shock wave is much stronger at large distances from the discharge than was previously believed. Consequently, the range of action of the lightning discharge via its shock wave, as it affects the shattering and freezing of supercooled hydrometeors, may be large.

E.P. Krider, G.A. Dawson and M.A. Uman, **"Peak Power and Energy Dissipation in a Single-Stroke Lightning Flash,"** J. Geophys. Res. 73, 3335 (1968). [May]

Abstract: A recent study comparing the acoustic output of a long air spark and lightning [*Dawson, et al.*, (1968)] required a reliable value for the average energy dissipated per unit length in a single lightning stroke. Previous estimates of this energy have depended on a knowledge of the average quantity of charge transferred per stroke and an educated guess at the potential difference between cloud and ground [*Malan*, (1963)]. In the present study, the peak radiant power and the total radiant energy emitted within a given spectral region by a single-stroke lightning flash are compared with those given off by a long spark whose electrical power and energy inputs are known with fair accuracy.

W.D. Hayes, **"Self-similar strong shocks in an exponential medium,"** J. Fluid Mech. 32, 305 (1968).

Abstract: The self-similar one-dimensional propagation of a strong shock wave in a medium with exponentially varying density and ray-tube area is studied, using the Eulerian approach of Sedov. Conservation integrals analogous to Sedov's are obtained, with the expression for the Lagrangian variable. Calculated results are compared with the predictions of the CCW (Chisnell, Chester and Whitham) approximation. It was found that, in contrast to the implosion case, the propagation parameter from the CCW approximation is in error by 15% or more.

W.D. Hayes, **"The propagation upward of the shock wave from a strong explosion in the atmosphere,"** J. Fluid Mech. 32, 317 (1968).

Abstract: A method is established for the calculation of the trajectories of shocks moving upward in the atmosphere, on the basis of the assumption that they are of the self-propagating type. The results of the calculations for self-similar motions are given, and these are used to establish a propagation law based upon the concepts of the Chisnell, Chester and Whitham (CCW) approximation. This propagation law enters a characteristics law based upon that proposed by Whitham, but reformulated for the computation of axisymmetric shocks with varying density.

An asymptotic self-preserving shock shape is investigated, and is computed for the case $\gamma = 1.4$. A parabolic approximation scheme suggested by the self-preserving solution is developed, in which the solution near the axis is reduced to the solution of a system of ordinary differential equations. Finally, the governing equation for the general case without axial symmetry (but without winds) is presented.

J. Capon, **"Investigation of Long Period Noise at LASA,"** Massachusetts Institute of Technology (Lexington Lincoln Laboratory) Technical Report No: TN-1968-15; ESD-TR-68-176, June 3, (1968). NTIS Number AD-671509.

Abstract: The long-period noise in the 20 to 40 second period range limits the identification level at which the surface-wave, body-wave discriminant can be applied at the Large Aperture Seismic Array (LASA). Therefore, an investigation was made to determine the sources and properties of this noise. Only the long-period vertical array at LASA was considered. Both conventional and high-resolution frequency-wavenumber spectra are presented for the noise, as well as coherence results. These data show that the noise consists of two components. One component propagates across the array as fundamental-mode Rayleigh waves and is known to be caused by the action of surf on coastlines. The other component is nonpropagating and evidence is presented which indicates it is caused by the elastic loading on the ground by the earth's atmosphere. This is established by correlating the power of the nonpropagating noise with the power on the microbarograph sensors at LASA. It is also shown that the signal-to-noise ratio gain obtained with maximum-likelihood processing relative to that obtained with beamforming for the long-period noise present at LASA, will not be substantial unless it can be shown that significant amounts of propagating noise power, relative to total noise power, are present. The results at LASA indicate that such large amounts of propagating noise power are rarely to be observed. [Descriptors: seismological stations; noise; earthquakes; Rayleigh waves; epicenter; seismometers; phased arrays; density; signal-to-noise ratio; geometry; power spectra; nuclear explosions; processing; integral transforms; resolution; Montana.]

N.K. Balachandran, "**Acoustic-Gravity Wave Propagation in a Temperature- and Wind-Stratified Atmosphere,**" J. atmos. Sci. 25, 818 (1968). [September]

Abstract: A theory of propagation of acoustic-gravity waves in a temperature- and wind-stratified atmosphere is developed. It is shown by using suitable wind structure in a COSPAR standard atmosphere that both the normal dispersion (group velocity increasing with period) and the inverse dispersion (group velocity decreasing as the period increases) of acoustic-gravity waves can be explained. It is found that winds of the order of 100 m sec^{-1} at about 100 km altitude are needed to account for inverse dispersion in the period range of about 5-15 min.

A.D. Pierce, "**Theoretical Source Models for the Generation of Acoustic-Gravity Waves by a Nuclear Explosion,**" in Symposium Proceedings: Acoustic-Gravity Waves in the Atmosphere, U.S. Government Printing Office, Boulder Colorado, July 15 - 17, Page 9, (1968).

Abstract: A generally accepted source model (as regards hydrodynamic effects) for a nuclear explosion is that of an initially small high temperature sphere of total energy E and initially of ambient density. Since the early history of the blast wave involves highly nonlinear effects, this model cannot be incorporated directly into a linear theory for the interpretation of far field microbarograms. The usual practice is for one to assume a decoupling between nonlinear effects and the combined gravitational and atmospheric effects, by selecting a linear source model with reference to computations of blast waveforms in a homogeneous atmosphere without gravity. Possible methods for incorporating source models into a linear formulation are discussed. Mass and energy point source models are compared as to their far field predictions. The two types of sources are formally equivalent when the explosion is near the ground but differ markedly as regards excitation of incompressible guided modes for above ground explosions. The applicability of point source models is argued to be valid for the interpretation of acoustic arrivals. They may not be applicable in the interpretation of the gravity wave even when the characteristic number $(E/p_o)^{1/3}g/c^2$ is small, as the computations neglecting gravity cannot be relied on to accurately predict the tail of the blast wave. A simple calculation indicates that as much energy as E/4 may be associated with the rise of the bubble created by wave transport of mass from the center of detonation. Qualitative implications of this are explored by examination of the fully linear acoustic-gravity initial value problem. The results suggest that (insofar as the gravity wave is concerned) a linear model with a point impulsive energy source may suffice. If this is true, then the waveform amplitude should be proportional to E and the waveform shape should be independent of E.

I. Tolstoy and T. Herron, "**Long Period Gravity and Acoustic Modes of the Lop Nor Thermonuclear Event of June 17, 1967,**" Columbia University (Dobbs Ferry NY, Hudson Laboratories) Technical Report No: TR-139; CU-165-68-ONR-266-PHYS, August (1968).

Abstract: Results obtained on the Hudson Laboratories long period microbarograph array for the Chinese thermonuclear explosion of June 17, 1967 are described. Of particular interest is the presence of a fast arrival, having a period of approximately 15 min and traveling with a speed of about 600 msec. This arrival is detected by beamforming techniques both for the short great circle path and for the long one. Also detected were

7- to 8-min periods traveling at 300 msec. [Descriptors: seismological stations; seismic waves ; nuclear explosions; China; detection; velocity; phased arrays; microseisms; gravity; magnetic fields.]

R.F. MacKINNON, **"Microbarographic oscillations produced by nuclear explosions as recorded in Great Britain and Eire,"** Quart. J. Roy. Meteor. Soc. 94, 156 (1968).

Abstract: A summary is presented of previously unpublished microbarograph data associated with atmosphere thermonuclear bomb tests in the Marshall Islands and in the Soviet Union from 1954 to 1962. Some effects of winds upon atmospheric pressure waves are indicated through a study of wind conditions over the paths of propagation and through comparison with reported Japanese data. It is shown that, as well as the speed of the waves, the maximum amplitudes of wave-trains depend upon wind conditions so that estimates of the size of explosions must take into account prevailing winds. The possible usefulness of microbarograms in the study of upper atmospheric winds is indicated.

A. Winn-Nielsen, **"A note on internal gravity waves in a hydrostatic compressible fluid with vertical wind shear,"** Tellus 20, 551 (1968).

Abstract: None.

J.D. Cole and C. Greifinger, **"Acoustic-Gravity Waves From an Energy Source at the Ground in an Isothermal Atmosphere,"** Rand Corporation Technical Report RM-5828-ARPA/AFT, December, (1968). [December]

Abstract: The pressure pulse generated in an isothermal atmosphere by an energy source at the ground is calculated from an integral representation of the pressure field previously derived by the authors. The shape of the signal is shown, as a function of time, at several distances from the source for a fixed altitude, and a several altitudes at a fixed lateral distance. The first signal to arrive at any location is a high-frequency acoustic wave, followed by a low-frequency acoustic-gravity wave. The onset of the latter is marked by a sharp front, or caustic. At any instant (after the arrival of the caustic), there are three principal components at any location, the lowest of which becomes dominant as time progresses. It is shown how the qualitative features of the flow, as well as the exact location of the caustic, can be obtained from kinematic theory.

E.E. Gossard, **"The Effect of Bandwidth on the Interpretation of the Cross Spectra of Wave Recordings from Spatially Separated Sites,"** J. Geophys. Res., Space Physics, 74, 325 (1969). [January]

Abstract: It is argued that the coherence between records from a triangle of stations can be used to deduce not only the effective beamwidths of gravity wave patterns but can also be used to obtain their velocity bandwidth throughout the wave spectrum and its effect on the apparent velocity of propagation. Relationships between the apparent velocity of wave propagation and the velocity bandwidth are derived; they are analogous to the cross correlation approach of Briggs, Phillips and Shinn but are herein generalized to include the frequency domain. The significance of the similarity hypothesis which is essential to the Briggs, Phillips and Shinn approach is discussed. The effect of the frequency bandwidth corresponding to the sampling rate and digital methods of analysis is considered in relation

to the apparent phase velocity. The analytical results are applied to experimental data on gravity wave motions in the D region of the ionosphere.

J.W. Reed, **"Operation Prairie Flat, Airblast Project Ln-106, Microbarograph Measurements, Final Report: 'Distribution of Airblast Amplitudes in the Ozonosphere Sound Rings,"** Sandia Laboratories Technical Report, February (1969). NITS Number SC-M-69-33.

Abstract: No abstract available. [Descriptors: nuclear explosions; simulation ; explosion effects; microbarometric waves; stratosphere; surface burst; propagation; Canada. Identifiers: Prairie Flat shot; ozonosphere]

G.R. Kaschak, **"Long-Range Supersonic Propagation of Infrasonic Noise Generated by Missiles,"** J. Geophys. Res., Space Phys. 74, 914 (1969). [March]

Abstract: None.

T.J. Herron and I. Tolstoy, **"Tracking Jet Stream Winds from Ground Level Pressure Signals,"** J. Atmos. Sci. 26, 266 (1969). [March]

Abstract: A major portion of atmospheric pressure fluctuations in the 30-90 min period range was observed to move across a small array of microbarographs with speeds and directions that correlate with jet stream winds. Measured speeds (10-50 m sec^{-1}) and periods, with plane wave assumptions, yield wavelengths of the order of 100 km. The pressure fluctuations were observed, however, to decorrelate in much less than one wavelength, implying that they are not *free* waves, but more likely are distributions dragged along by the tropopause winds.

I. Tolstoy and T.J. Herron, **"A Model for Atmospheric Pressure Fluctuations in the Mesoscale Range,"** J. Atmos. Sci. 26, 270 (1969). [March]

Abstract: It is shown, given perturbations of the jet stream wind system similar to those reported from balloon and aircraft studies, that it is possible to calculate ground level pressure fluctuations. Using a density stratified model of the troposphere and a constant gravity field, and assuming the jet stream to act as a traveling disturbance, a simple linear model predicts the correct order of magnitude and power spectra for microbarographic fluctuations in the 5-60 min period range.

T.J. Herron, I. Tolstoy and D.W. Kraft, **"Atmospheric Pressure Background Fluctuations in the Mesoscale Range,"** J. Geophys. Res. 74, 1321 (1969). [March]

Abstract: A study of mesoscale-range pressure fluctuations on a large (250-km) array of microbarographs has shown a correlation of seasonal pressure spectrum levels with horizontal distance from occasional synoptic-scale weather disturbances that are concentrated into short intervals of time (at most a few tens of hours). A lower-level but more continuous source of pressure background results from waves generated directly by jet-stream perturbations. These waves correlate in velocity and direction with the jet-stream winds over the array.

W.L. Jones, **"Ray Tracing for Internal Gravity Waves,"** J. Geophys. Res. 74, 2028 (1969). [April]

Abstract: Ray-tracing techniques are applied to internal gravity waves in a fluid with spatially varying mean flows. It is shown that the general effect of deformational mean flow over long time periods is to shorten the wavelength, the effect being most pronounced for waves of modest spatial scale.

I. Tolstoy and J. Engelhardt, **"Note on Long Gravity Waves in Layered Atmospheres,"** J. Geophys. Res. 74, 3436 (1969). [June]

Abstract: None.

M.E. Austin and W.M. Ross, **"Ray Tracing in a Sectioned and Layered Atmosphere Using a Shifting Coordinate System,"** IEEE Trans. Geoscience Electronics GE-7, 157 (1969). [July]

Abstract: Acoustical ray tracing in a horizontally layered and vertically sectioned atmosphere is accomplished on a digital computer using a shifting Cartesian coordinate system. The atmosphere is divided into vertical layers. In each of these layers straight line approximations of the variation of the speed-of-sound curve with altitude are used, thereby generating a constant radius of curvature for the acoustic ray path in each layer. Sectioning of the atmosphere is performed by allowing boundary lines to emanate outward from the earth's center through the atmosphere. Ray points are established whenever the ray path intersects either a layer boundary or a section boundary.

The computer program, called RAYTRACE, prints the X,Y, and Z coordinates of each ray point referenced to a planar coordinate system with origin at the ray path's beginning as well as the time required for the ray to travel to each ray point. Range versus altitude and range versus drift plots are made of the ray path and the effects on these curves of variations of the initial elevation and azimuth angles of the ray are discussed.

W.W. Troutman, **"Numerical Calculation of the Pressure Pulse from a Lightening Stroke,"** J. Geophys. Res. 74, 4595 (1969). [August]

Abstract: None.

Yih-Ho Pao, **"Spectra of internal waves and turbulence in stratified fluids. 1. General discussion and indications from measurements in stably stratified atmosphere and ocean,"** Radio Science 4, 1315 (1969). [December]

Abstract: A unified spectral description of internal waves and turbulence in a stably stratified atmosphere or ocean is proposed. We envisage that the fluctuating motions in a free atmosphere with scales smaller than the synoptic scale consist of internal waves and turbulence. At low wavenumbers, internal waves predominate; this range of wavenumbers may be called the internal wave subrange. The internal waves can be identified from the characteristics of velocity-scalar cospectra and quadrature spectra, as shown recently by *Pao* (1969) in a laboratory experiment. When the internal waves are sufficiently strong and distinct, the different harmonics of internal waves may appear in the autospectra of velocity

and temperature where the peaks and valleys are clearly identifiable. This, we believe, explains the presence of peaks and valleys in some velocity autospectra of clear air turbulence measured in strongly stratified regions of the atmosphere. At intermediate wavenumbers (buoyant subrange) the buoyancy effect is still strong but the turbulent scrambling process also becomes important; the higher-order harmonics of internal waves are no longer distinct and cannot be detected in the autospectra; the velocity autospectra are steeper than $k^{-5/3}$. At high wavenumbers (inertial and viscous subranges) turbulence predominates. The characteristics of the fluctuating motion in this range of wavenumbers can be described well with Kolmogorov's concept of local isotropy and are not affected by stratification. The proposed spectral behavior for the free atmosphere is described in detail and supported with existing measurements in stably stratified regions of the atmosphere and ocean in part 1. It will be further supported by our laboratory experiments on the breaking of internal waves in a two-fluid system [*Hall and Pao*, 1969] in part 2.

C.J.R. Garrett, "**Atmospheric edge waves,**" Quart. J.R. Met. Soc. 95, 731 (1969).

Abstract: In an isothermal windless atmosphere Lamb's wave, the energy of which decays exponentially with height, propagates non-dispersively with the speed of sound. In the real atmosphere the speed of sound and the wind speed vary with height, but it is known that an edge wave similar to Lamb's wave is still possible. Assuming the wind speed and variations in the speed of sound to be much less that some typical sound speed, this atmospheric edge wave is shown to have group velocity given approximately by

$$c_g = <c>\left(1 - 3D\frac{\omega^2}{<c>^2}\right)$$

where ω is the wave frequency, $<c>$ is the mean of the sound and wind speeds weighted with the energy density of the basic Lamb wave, and D is a positive dispersion coefficient defined in terms of a simple integral of the departures of the sound and wind speeds from their weighted means. Expressions are derived for the dispersive effect of a change in the sound or wind speed at any height, and these are evaluated for a particular model atmosphere. It is shown that the effect of horizontal inhomogenieties in the atmosphere is merely to average the long wave speed and dispersion coefficient along the great circle path from source to receiver. The theory is compared with the results obtained from microbarograms of pressure pulses from large atmospheric explosions, but it is found that the paucity of atmospheric data makes it difficult to use these results to estimate winds above sounding heights on the path from the source to receiver. Atmospheric edge waves are shown to be rather insensitive to the upper boundary condition in general, through the effect of microbarograms of coupling between the edge wave and waves propagating high in the atmosphere is discussed, and various decoupling mechanisms, including dissipative decoupling, are described.

F.P. Bretherton, "**Lamb waves in a nearly isothermal atmosphere,**" Quart. J.R. Met. Soc. 95, 754 (1969).

Abstract: If the variations in sound speed c(z) and wind u(z) with height z are not too great, there is a mode of propagation of acoustic waves in the atmosphere in which the wave energy E(z) decreases exponentially with z with a scale $c_0^2/(2-\gamma)g$ (about 16 km), and the phase speed c_m is given approximately by

$$c_m^2 = \frac{\int_0^\infty dz\,(c+u)^2 E(z)}{\int_0^\infty dz\, E(z)}$$

(about 300 m s^{-1}).

A.A. Few, **"Power Spectrum of Thunder,"** J. Geophys. Res. 28, 6926 (1969). [December]

Abstract: A model for the sound generated by a tortuous lightning channel is proposed that describes the principal features of thunder. The model indicates that the power spectrum of thunder should be similar to the power spectrum produced by a short line segment having the same energy-per-unit length E_l as the most energetic return stroke in the lightning flash. This model also predicts that E_l can be estimated from a measurement of the frequency of the peak in the power spectrum of thunder f_m; the relationship is $f_m = (0.63)C_o(P_o/E_l)^{1/2}$, where P_o and C_o are the ambient pressure and sound speed.

J.W. Reed, **"Climatology of Airblast Propagations from Nevada Test Site Nuclear Airbursts,"** Sandia National Laboratory Report SC-I.R.-69-572m December, (1969). [December]

Abstract: Microbarograph data from Nevada atmospheric nuclear tests of 1951-1962 have been assembled to show climatological patterns for long range propagations. Amplitudes have been normalized to 1-kiloton yield, free-airburst, after actual height-of-burst effects were removed.

On-site propagations under early morning inversions often showed double the amplitudes expected for standard hemispherical wave expansion. These enhanced blasts were blocked by mountains and did not penetrate off-site. Strong winds at higher altitudes gave as much as 5X blast magnifications at Indian Springs and Las Vegas.

Ducting at very high altitude, to 30 miles or 150,000 feet, is seasonally directed eastward in winter, westward in summer. Resulting amplitudes in the sound ring near 135 miles range show as large as 3X the magnification downwind and 0.006X reduction upwind. On the average the annual cycling in east and west directions ranges from near standard, 1X, downwind amplitudes to 0.016X upwind amplitudes. The seasonal reversal periods when upper winds are nearly calm, occur about May 5 and September 20. At that time amplitudes in all directions show an average 0.28X reduction below standard.

T.G. Varghese and V. Kumar, **"Detection and Location of an Atmospheric Nuclear Explosion by Microbarograph Arrays,"** Nature 225, 259 (1970). [January]

Abstract: None.

I. Tolstoy and T.J. Herron, **"Atmospheric Gravity Waves from Nuclear Explosions,"** J. Atm. Sci. 27, 55 (1970). [January]

Abstract: Atmospheric gravity waves excited by nuclear explosions were recorded on several occasions during the period 1967-68, on a large aperture (250 km x 200 km) array of long-period microbarographs (1 - 60 min period pass-band) in the New York - New Jersey area. The spectrum of these waves peaks near a period of 15 min and their average group velocity (- 600 m/s), their dispersion and attenuation conform to theoretical predictions, for the surface mode.

I. Tolstoy and P. Pan, **"Simplified Atmospheric Models and the Properties of Long-Period Internal and Surface Gravity Waves,"** J. atmos. Sci. 27, 31 (1970). [January]

Abstract: Two- and four-layer models of the atmosphere up to heights of about 500 km allow a systematic and fairly accurate account of the far-field properties of guided internal and surface gravity waves having periods>10 min. Simple formulae and numerical results are given for a variety of models allowing one to determine the importance of such effects as compressibility, free vs rigid boundaries, layering, and the earth's rotation. The importance of coupling effects similar to those occurring in layered acoustic and electromagnetic waveguides is emphasized. It is also shown, the period pass-band between 10 and 200 min, that there is in all models a difference between surface and internal wave group velocities of sufficient magnitude to preclude confusion in the travel times of these modes. It is also stressed that the layer of atmosphere between altitudes of 110 and 150 km, in which the Vaisala frequency may exceed the acoustic cut-off frequency, plays a critical role in determining the amplitude of the ground-level pressure perturbations associated with the passage of a surface gravity wave. This amplitude is sensitive to the precise laws of atmospheric stratification as well as to wind shear fields at these heights. It is shown that our assumptions concerning the nature of the "effective free surface" of the atmosphere are at least consistent with the damping of 15 min period, 600 m sec^{-1} pressure waves observed in connection with large nuclear explosions in 1967 and 1968.

E. E. Gossard and D.B. Sailors, **"Dispersion Bandwidth Deduced from Coherency of Wave Recordings from Spatially Separated Sites,"** J. Geophys. Res., Space Physics, 75, 1324 (1970). [March]

Abstract: In an earlier paper it was pointed out that temporal variability in the dispersive properties of the propagation medium can cause a band of wave velocities to be associated with each frequency component in the time series of a sampled quantity. This results in degrading the coherence between stations separated in the direction of propagation and can cause significant error in the apparent wave velocity as deduced from the phase of the cross spectra. This bandwidth is complementary to the concept of beamwidth, which principally degrades the coherence between stations separated perpendicular to the direction of propagation. The present paper uses numerical procedures to extend the earlier results to larger beamwidths and bandwidths.

J.F. Claerbout and L. Lee, **"Microbarograph Studies,"** Stanford University Technical Report No: AFOSR-70-1689-TR, May 13, (1970). NTIS Number AD-707875.

Abstract: Theoretical work included mathematical-computational simulation of an air wave propagating around the earth. The effect of horizontal variations of wind and temperature was included. These explain the severe defocusing always observed at the antipodes. Observational work included installation and operation of an LTV-LASA type

microbarograph. Regular inspection of the records revealed a nuclear explosion and numerous incompletely understood meteorologic phenomena. Computer programs have been written and documented for reading LASA data tapes and Stanford data tapes. [Descriptors: microbarometric waves; propagation ; sound signals; jet streams (meteorology); barometric pressure; wind; simulation; atmospheric temperature; computer programs.]

N.K. Balachandran, **"Effects of Winds on the Dispersion of Acoustic-Gravity Waves,"** J. Acoust. Soc. Am. 48, 211 (1970). [July]

Abstract: The influence of winds at various levels in the atmosphere on the propagation of acoustic-gravity waves is studied theoretically using dispersion curves for various atmospheric models. It is found that short-period waves (periods less than about 400 sec) are influenced mainly by winds close to the ground, whereas long-period waves (periods more than about 400 sec) are influenced by high-altitude as well as low-altitude winds. Strong winds at altitudes near 100 km in the direction of propagation of the waves and winds near the ground blowing in a direction opposite to that of the waves are found to be favorable for inverse dispersion in group velocities at long periods. Exactly opposite wind conditions favor normal dispersion at all points.

H.A. Montes, C.E. Grosch, M.J. Hinich and E.S. Posmentier, **"Atmospheric Propagation Studies Up to 30 September 1969,"** Teledyne Isotopes (Westwood, NJ) Technical Report No: IWL-7556-175; AFOSR-70-2734TR, July (1970). NTIS Number AD-716541.

Abstract: A summary is given of significant results obtained during the research effort corresponding to the period 1 September 1968 - 30 September 1969. Particular emphasis was given to the construction of a phase-path Doppler sounder array. Signals detected by the microbarograph array on the occasion of the Chinese nuclear test of 29 September 1969 are compared with signals from previous tests. There appears to be a seasonal effect on the propagation and/or bandwidth of these signals. Preliminary work on ionospheric motion background using phase-path sounder data indicates that the background activity can be broadly separated into two period ranges: periods longer and shorter than 5 minutes. The shorter periods appear to have a hydromagnetic origin while the longer periods are probably due to internal gravity wave activity. A theoretical investigation of the interaction between instability waves and internal gravity waves in the atmosphere showed that internal gravity waves are trapped within a layer where the shear flow velocity is greater than the speed of sound and that the phase velocity of the internal gravity waves is approximately equal to the maximum velocity of the shear flow. [Descriptors: microbarometric waves; detection; nuclear explosions; detection; Doppler systems; barometers; gravity; sound signals; power spectra; hydrodynamics. Identifiers: internal gravity waves; geomagnetic micropulsations; infrasonic radiation; NTISAF.]

H. Matheson, **"Research in Geoacoustics and Seismology,"** NOAA (Rockville, MD) Technical Report No: AFOSR-70-2564TR, September (1970). NTIS Number AD-715886.

Abstract: The Geoacoustics Group of the Environmental Research Laboratories sponsors and monitors a geoacoustics network in the United States, South America, and Israel. Data from these stations is used to carry out a systematic search of all received analog magnetic tape records. Proper interpretation of the results of this search will

lead to a better understanding of the vagaries of atmospheric propagation and of naturally occurring sources of infrasound. [Descriptors: seismology; reports ; microbarometric waves; detection; seismometers; detectors; networks; nuclear explosions; underground explosions; digital recording systems; magnetic tape; data processing systems; maintenance. Identifiers: Infrasonic radiation; NTISAF.]

H.A. Montes, "**Atmospheric Propagation Studies up to 30 September 1970,**" (Final summary rept. 1 Oct 69-30 Sep 70) Teledyne Isotopes (Westwood N J) Technical Report No.: IWL-7556-220; AFOSR-TR-71-1207, November (1970). NTIS Number AD-723319.

Abstract: The phase-path (Doppler) sounder array was expanded to operate at two sounding frequencies simultaneously. Particular emphasis was given to the study of ionospheric background motions having periods longer than 5 minutes or so. It was found that the power spectra of the phase-path variations show the effect of a varying Vaisala frequency with height, probably modified by the effects of viscosity. It has also pointed out the potential of the Doppler technique to measure the parameters of the neutral gas structure at ionospheric altitudes. Cophase analysis of phase-path records following Saturn-Apollo launches indicate that rocket generated infrasound is trapped at ionospheric heights by a wave-guide mechanism. Ionospheric motions detected by the Doppler array following a large earthquake are found to have a phase velocity equal to that of seismic Rayleigh waves of the same period and to arrive from the direction of the epicenter. A study of the spatial coherence of ionospheric motions indicates reflection point separations of the order of 60 km are sufficient for noise decorrelation up to periods of 30 min; and separations of 90 to 100 km for periods longer than 30 min. Preliminary analysis of microbarograph records following some of the French tests of 1970 show arrivals of long period gravity waves with phase velocities of the order of 550 m/sec. [Descriptors: microbarometric waves; detection; nuclear explosions; microbarometric waves ; atmospheric motion; ionosphere ; manned spacecraft; launch vehicles(Aerospace); launching; earthquakes; Doppler effect. Identifiers: Apollo; Saturn launch vehicles; Apollo 12 spacecraft; Apollo 13 spacecraft; infrasonic radiation; gravity waves; NTISAF.]

D. Cotton and W.L. Donn, "**Sound from Apollo Rockets in Space,**" Science 171, 565 (1971).

Abstract: Low-frequency sound has been recorded on at least two occasions at Bermuda with the passage of Apollo rocket vehicles 188 kilometers aloft. The signals, which are reminiscent of N-Waves from sonic booms, are (i) horizontally coherent; (ii) have extremely high (supersonic) trace velocities across the tripartite arrays; (iii) have nearly identical appearance and frequencies; (iv) have essentially identical arrival times after rocket launch; and (v) are the only coherent signals recorded over many hours. These observations seem to establish that the recorded sound comes from the rockets at high elevation. Despite this elevation, the values of surface pressure appear to be explainable on the basis of a combination of a kinetic theory approach to shock formation in rarefied atmospheres with established gas-dynamics shock theory.

J.W. Reed, "**Project Gondola III. Phase II. Microbarograph Measurements,**" Sandia Laboratories Technical Report PNE-1118, June (1971). NTIS Number: ADA741359.

Abstract: Four microbarograph stations recorded waves at a range of approximately 130 mi from a row charge of high explosives buried near optimum cratering depth. Comparison with propagations from three airburst calibration detonations showed that a source model derived from close-in data was appropriate for distant effects predictions. This model predicted that wave amplitudes from explosives at this scaled depth would be 20% of amplitudes expected for a free air burst. All amplitudes perpendicular to a row charge are proportional to the 0.7 power of the number of charges in the row. [Descriptors: nuclear explosions; shale; nuclear industrial applications; cratering; simulation; charges (explosive); underground explosions; pressure; networks; Mathematical models; Wind; Hazards; Damage assessment; Montana. Identifiers: Pre-Gondola 3 project; Plowshare operation; nuclear excavation; NTISA.]

J.W. Posey and A.D. Pierce, **"Estimation of Nuclear Explosion Energies from Microbaragraph Records,"** Nature 232, 253 (1971). [July]

Abstract: None. But paper presented an interesting relationship on estimating the energy release from an explosion detonated in the atmosphere. The expression provided is:

$$E = 13\, p_{FPT}\, [r_e \sin (r/r_e)]^{1/2} H_s\, (cT_{1,2})^{3/2}$$

where E is the energy release (1 MT = 4.2×10^{22} ergs), p_{FPT} is the first peak to trough pressure amplitude, r_e is the radius of the earth, r is the great circle distance from the burst point to the observation point, H_s is a lower atmospheric scale height, c is the sound speed and $T_{1,2}$ is the time interval between the first and second peaks.

C.H. Liu and K.C. Yeh, **"Excitation of acoustic-gravity waves in an isothermal atmosphere,"** Tellus 23, 150 (1971).

Abstract: The excitation of acoustic-gravity waves in an isothermal atmosphere is considered in this paper. It is shown that the excitation due to mass production, momentum production and heat production can be discussed by examining the same differential equation. The sources are assumed to be extended and vary both in time and in space. Asymptotic methods are used to obtain analytic expressions for the radiation field for all times, from the arrival of precursors to any time thereafter. It is found that the transient response results from contributions from one, two or all three modes depending on the times from the arrival of precursors. The three modes are the high frequency acoustic mode, the intermediate frequency buoyancy mode and the low frequency gravity mode. Additional features of the transient behavior depend on the temporal as well as spatial variation of the sources. An example is given for which numerical computations are made. Possible applications of the results to geophysical problems are discussed and certain extensions of the results are proposed.

W.C. Meecham, **"On aerodynamic infrasound,"** J. Atm. Terr. Phys. 33, 149 (1971).

Abstract: We consider atmospheric pressure variations in the period range from a few seconds to a few minutes. These pressure fluctuations arise (a) from local hydrodynamic effects which are estimated; (b) from nonpropagating pressure effects associated, for example, with a jet stream; (c) from propagating pressure effects associated with

aerodynamic infrasound. Following standard aerosonic theory, which is briefly reviewed here, the intensity of aerodynamic sound is estimated. The estimated amount of power radiated by aerodynamic sources, chiefly fluctuating winds at high altitude, is approximately that observed in noise measurements on the ground. Comparison is made between these theoretical estimates and observed pressure fluctuations in the low frequency range.

R.K. Cook and A.J. Bedard, **"On the Measurement of Infrasound,"** Geophys. J.R. astr. Soc. 26, 5 (1971).

Abstract: The physical properties and propagation of atmospheric infrasound determine the techniques and instrumentation used for its measurement. The physical properties which influence the design of the measurement system for infrasound are summarized, and the techniques and instrumentation used for measurement are described. Propagation over long distances is influenced by temperature gradients and winds. Therefore a network of infrasonic stations has been established on a world-wide basis to carry on propagation researches. Investigators at the observatories have identified various geoacoustical sources of infrasound. This paper provides a description of the basic measurement system used at all of the stations in the network.

E. Herrin and J.A. McDonald, **"A Digital System for the Acquisition and Processing of Geoacoustic Data,"** Geophys. J.R. astr. Soc. 26, 13 (1971).

Abstract: In the autumn of 1969 we accepted delivery of three TC-2000 digital data acquisition systems from Teledyne Geotech. These systems can record up to 16 channels of long period, digital data with a specified sampling rate (currently 1 per second) on magnetic tape in a 'IBM compatible' format. Identifying headers are automatically written at the beginning of each file on tape and Universal Time is written each minute. The actual dynamic range of 120 dB is automatically assured by the use of binary, gain ranging amplifiers. The systems have been tested and are now operating satisfactorily at Blacknest Laboratory near Reading in England, at the University of Alaska and a field site east of Dallas, Texas.

A.U. Kerr, **"Digital Computer Programs for Recording and Processing Infrasonic Array Data,"** Geophys. J.R. astr. Soc. 26, 21 (1971).

Abstract: We describe in detail the digital formats in which microbarograph array data are recorded at Alexandria Laboratories. Brief summaries are presented of 32 computer programs for altering the data formats, performing signal detection and analysis in both the time domain and the frequency-wavenumber domain, and for various theoretical calculations involving the acoustic radiation from explosion sources in a layered atmosphere. An example is included of the write-ups and flow charts of these programs.

F.H. Grover, **"Experimental Noise Reducers for an Active Microbarograph Array,"** Geophys. J.R. astr. Soc. 26, 41 (1971).

Abstract: Brief outlines are given of the problem of identifying low frequency acoustic waves from atmospheric background noise and of the methods used by UKAEA to improve detection of these waves.

An important aspect of the experimental work has been to develop devices to reduce atmospheric pressure noise, suitable for use at existing microbarograph recording sites, and to evaluate their performance in field tests. Some interim results from these experiments are given.

R. Burridge, "**The Acoustics of Pipe Arrays,**" Geophys. J.R. astr. Soc. 26, 53 (1971).

Abstract: A theoretical analysis is given for the acoustical behaviour of the pipe-microbarograph systems used to detect acoustic gravity waves and other modes of infrasound. It is shown how to compute the response of the microbarograph to a fluctuation pressure at any one inlet port of the pipe and how the results of such computations may be used to calculate the response to a plane sound wave traversing the system.

The analysis is illustrated by numerical examples obtained by means of a computer program. These examples confirm that the tapered tube modelled after Daniels' line microphone has very good characteristics, but that good results may also be obtained using pipes of uniform bore. The work leans heavily on Benade's calculations of sound propagation in a circular conduit.

J.A. McDonald, E.J. Douze and E. Herrin, "**The Structure of Atmospheric Turbulence and its Application to the Design of Pipe Arrays,**" Geophys. J.R. astr. Soc. 26, 99 (1971).

Abstract: Turbulent boundary layers at the surface of the Earth limit the detection of infrasonic waves with periods greater than 1 s. Pipe arrays designed to improve the signal-to-noise ratios of infrasonic waves usually assume that the background noise due to this turbulent boundary layer is incoherent between the array inlets. The power at various points on a surface was measured; coherences between these points were determined and they were found to be significant in the period range 1-100 s. Such coherent noise must be considered when pipe arrays are designed.

W.L. Donn and D. Rind, "**Natural Infrasound as an Atmospheric Probe,**" Geophys. J.R. astr, Soc. 26, 111 (1971).

Abstract: For four years continuous recording of infrasonic signals in the frequency range 0.1 Hz to 1 Hz, known as microbaroms, has been conducted at Palisades, New York. The microbaroms we recorded are radiated into the atmosphere by interfering ocean waves in the North Atlantic as far as 2000 km away. A characteristic diurnal variation in the amplitude of the received signal has been noted, independent of any variation in the source. We conclude that the variation is due to variations of the factors affecting atmospheric sound propagation, namely wind and temperature.

In winter a semidiurnal variation in signal amplitude is observed, with maximum reception around 11:00 and 22:00 local time. Reference to wind and temperature observations in the literature shows that at these times the lowest level of reflection of the vertically propagating signal occurs between 100 and 110 km due to the presence of strong east winds. At 18:00, time of minimum amplitudes, the reflection level rises to about 115 km because of a change in tidal wind phase. Viscous dissipation associated with the changed reflection height can account for the observed signal weakening. A third maximum, a less regular effect, is found to be related to more variable winds between 95 and 105 km.

In summer, reflection is found to occur from about 50 km due to the presence of stratospheric easterlies. The summer diurnal variation, different from that of the winter, exhibits only a weak minimum about 20:00. This appears to result from a diurnal temperature variation superimposed on a diurnal wind variation. Abnormally high microbaroms were recorded at times that can be related to an atmospheric event known as a stratospheric warming. Microbaroms thus provide a continuously available natural mechanism for probing the upper atmosphere. We conclude that the establishment of microbarom observation systems could give a comprehensive technique for monitoring several upper atmospheric parameters.

N.K. Balachandran and W.L. Donn, "**Characteristics of Infrasonic Signals from Rockets,**" Geophys. J.R. astr. Soc. 26, 135 (1971).

Abstract: Infrasound has been recorded at long range from the launch and the re-entry of the first stage booster of Saturn V rockets. Detailed study has been made with the use of an acoustic ray-tracing procedure that involved actual temperature and wind data at the launch site and along the propagation path. Details of signal arrival times and duration are shown to be controlled by the nature of the ground-based sound channel, which in turn is determined by the atmospheric structure below about 60 km. Fluctuations in signal amplitude are explained on the basis of interference of acoustic rays.

D.E. Cotten, W.L. Donn and A. Oppenheim, "**On the Generation and Propagation of Shock Waves from Apollo Rockets at Orbital Altitudes,**" Geophys. J.R. astr. Soc. 26, 149 (1971).

Abstract: Acoustic signals from Apollo rockets at orbital altitude (188 km) appear to be explainable with the assumption that the exhaust plume serves as a conical body of large cross-section moving supersonically with the rocket. The presence of the surface signal (1-3 Hz and higher) implies that propagation in the upper atmosphere occurred as an N-wave shock cone without the strong attenuation to which an acoustic wave or even a saw-toothed (shocked) wave of similar frequency would be subjected. The shock cone does not attenuate because energy is continually re-supplied along the shock cone from the vehicle and its plume acting as a piston. Calculated overpressures do not reduce to acoustic amplitudes until the wave is below 40 km where acoustic attenuation becomes negligible.

W.L. Donn, Ilmars Dalins, Vincent McCarty, Maurice Ewing and George Kaschak, "**Air-Coupled Seismic Waves at Long Range from Apollo Launchings,**" Geophys. J.R. astr. Soc. 26, 161 (1971).

Abstract: Microphones and seismographs were co-located in arrays on Skidaway Island, Georgia, for the launchings of Apollo 13 and 14, 374 km to the south. Simultaneous acoustic and seismic waves were recorded for both events at times appropriate to the arrival of the acoustic waves from the source. Significant comparisons of the true signals are (1) the acoustic signal is relatively broadband the nearly monochromatic seismic signal; (2) the seismic signal is much more continuous than the more pulse-like acoustic signal; (3) ground loading from the pressure variations of the acoustic waves is shown to be too small to account for the seismic waves; (4) the measured phase velocities of both acoustic and seismic waves across the local instrument arrays differ by less than 6 per cent and possibly 3 per cent if experimental error is included. It is concluded that the seismic waves are generated by resonant coupling to the acoustic waves along some 10 km of path on Skidaway Island. The thickness of unconsolidated sediment on the island is appropriate to

resonant ground wave frequency of 3.5 to 4 Hz, as observed. Under appropriate conditions, ground wave observations may prove more effective means of detecting certain aspects of acoustic signals in view of the filtering of wind noise and amplification through resonance.

E.S. Posmentier, **"Preliminary Observations of 1-16 Hz Natural Background Infrasound and Signals from Apollo 14 and Aircraft,"** Geophys. J.R. astr. Soc. 26, 173 (1971).

Abstract: Infrasound with frequencies of 1-16 Hz, detected by an array of four thermistor flow-meter microphones in Sterling Forest, New York, was observed to have a continuous background with peak energy distributed near 16 Hz in frequency, with amplitudes of about 1 dyne/cm^2, and arriving from the south-west and south-east at slightly above the speed of sound in air at ground level. The same array of microphones detected 5 dyn cm^{-2} signals from the Apollo 14. The earlier part of the 10-min signal arrived from the first stage re-entry, the later from the launch site vicinity. It is shown that aircraft beyond the visible and audible range can be detected and tracked by monitoring the infrasound emitted throughout most of the 1-16 Hz frequency band.

C.R. Wilson, **"Auroral Infrasonic Waves and Poleward Expansions of Auroral Substorms at Inuvik, N.W.T., Canada,"** Geophys. J.R. astr. Soc. 26, 179 (1971).

Abstract: Observations at Inuvik (70.4^{o} dipole latitude) have shown that supersonic motions of auroral arcs that sweep across the zenith from south to north during poleward expansions of auroral substorms do not generate observable auroral infrasonic waves. This is in contrast to the fact that equator ward supersonic motions of similar auroral arcs do produce large amplitude infrasonic bow waves. These results imply an asymmetry in the basic generation mechanism of infrasound with the auroral electrojet arcs.

R.W. Procunier, **"Observations of Acoustic Aurora in the 1-16 Hz Range,"** Geophys. J. astr. Soc. 26, 183 (1971).

Abstract: Acoustic aurora have been heard by long-term residents of the Arctic. They have also been recorded on microbarographs. Acoustic events associated with aurora are now reported in the near infrasonic range (1-16 Hz) at Barrow, Alaska. These observations were made with the aid of a resonant detector achieving a high signal-to-noise ratio similar to that used in extending the rocket-grenade technique to 109 km. Over 100 impulsive events of a quasi-repetitive nature were recorded on a patrol basis during January 1970. Acoustic events were correlated with disturbed magnetic conditions and optical aurora but uncorrelated with lower-frequency auroral microbarograph events at College or Inuvik.

It is hoped that these initial observations will persuade interested parties to a more complete study of this phenomena and encourage an explanation of the generation mechanism for auroral infrasonic waves.

R.K. Cook, **"Infrasound Radiated During the Montana Earthquake of 1959 August 18,"** Geophys. J.R. astr. Soc. 26, 191 (1971).

Abstract: Seismic waves caused by earthquakes radiate infrasound into the atmosphere as they proceed over the Earth's surface. Several instances of such sound waves radiated locally be seismic waves passing through the Washington, D.C. area have been observed at the infrasonic station there. A notable instance was the great Montana earthquake of 1959 August 18. Measurements of the radiated infrasound gave data on the seismic waves, including their travel times, local speeds, directions of travel, amplitudes, and waveforms.

R. Cabre', J. Rubin de Celis and J. Flores, **"Some Notes on Discrete Trains of Infrasonic Waves Produced by Point Sources,"** Geophys. J.R. astr. Soc. 26, 199 (1971).

Abstract: None. Paper presents microbarograph data of Soviet explosions recorded at La Paz, Bolivia.

R.J. Larson, L.B. Craine, J.E. Thomas and C.R. Wilson, **"Correlation of Winds and Geographic Features with Production of Certain Infrasonic Signals in the Atmosphere,"** Geophys. J.R. astr. Soc. 26, 201 (1971).

Abstract: Of the waves which propagate in the atmosphere at acoustic velocity in the period range from 10 to 100 s, one type has been classified by triangulation as arising principally from mountain regions. These signals were first described as 'northwesters' or '310 ers' by the NBS Geoacoustics Group under R.K. Cook at Washington, D.C., from the predominant direction of arrival. Subsequent operation of an observatory at Boulder, Colorado by Vernon Goerke gave a source region by triangulation in the Pacific Northwest, primarily in Montana and Alberta. Installations of observatories at College Alaska (Wilson) and Pullman, Washington-Moscow, Idaho (Craine and Thomas) enlarged the data base available, and triangulation showed the principal source areas to be along the coast of British Columbia-Alberta border. This paper discusses the presently known characteristics of this class of infrasonic waves, locates the triangulation areas, reviews selected events, and suggests that certain of these waves are produced as aerodynamic sound. The paper shows a correlation between the 500 mb jet stream velocity and direction in these mountainous regions, and the detection of these atmospheric pressure waves.

H.S. Bowman and A.J. Bedard, **"Observations of Infrasound and Subsonic Disturbances Related to Severe Weather,"** Geophys. J.R. astr. Soc. 26, 215 (1971).

Abstract: During the past 10 years the Geoacoustics Group of NOAA's Wave Propagation Laboratory studied travelling low-frequency pressure variations related to thunderstorms and severe weather. Two general categories of waves were associated with severe weather conditions: 'subsonic' pressure disturbances and infrasonic waves with acoustic velocities. The low-frequency pressure variations were measured at the Earth's surface using microphone arrays located at times thousands of kilometers from the severe-weather disturbance. The radiated infrasound was related to thunderstorms penetrating the tropopause and spectral analyses were performed on several signals. Possible practical applications to storm warning and classification are discussed for both infrasound and 'subsonic' pressure disturbances. Past measurements of these signals are reviewed.

T.M. Georges, **"An 'Ionospheric Weather' Index,"** Geophys. J.R. astr. Soc. 26, 243 (1971).

Abstract: None. The paper provides a method for deriving a daily 'ionospheric weather' index for a particular location.

E. Smart, "**Erroneous Phase Velocities from Frequency-Wavenumber Spectral Sections,**" Geophys. J.R. astr. Soc. 26, 247 (1971).

Abstract: Two-dimensional cross-sections of finite frequency-wavenumber spectra can easily be misinterpreted, since leakage of energy occurs along lines of constant wavenumber. In particular, the signal phase velocity determined from measurements on cross-sections normal to the frequency axis can be incorrect. We discuss an algorithm which corrects this situation. Examples using real and synthetic data are given.

H. Mack and E.A. Flinn, "**Analysis of the Spatial Coherence of Short-Period Acoustic-Gravity Waves in the Atmosphere,**" Geophys. J.R. astr. Soc. 26, 255 (1971).

Abstract: The coherence of atmospheric acoustic-gravity waves has been measured in the period range 10-100 s at the Large Aperture Microbarograph Array in south-eastern Montana. The acoustic-gravity waves observed were signals generated by presumed nuclear explosions. The decrease of coherence with increasing distance between pairs of microbarographs is less rapid in the direction of wave propagation than transverse to it. Variation of direction of arrival over a small range of azimuth ($\pm$ 5°) explains the spatial behaviour of coherence in the direction normal to the wave propagation. Both effects may be due to inhomogenieties in the atmosphere; the velocity of variation may be due to the presence in the signal of several normal modes of acoustic-gravity waves, each travelling at a slightly different phase velocity in the range 300-330 m s^{-1}.

H.A. Montes and E.S. Posmentier, "**Co-Phase Analysis of Atmospheric Wave Data,**" Geophys. J.R. astr. Soc. 26, 271 (1971).

Abstract: Co-phase is a statistic designed for the detection and parameter estimation of signals by detector arrays. Ionospheric motions detected by an array of four phase-path sounders following a large earthquake are found by the co-phase technique to have a phase velocity equal to that of seismic Rayleigh waves of the same period, and to arrive from the direction of the epicentre. The calculation of co-phase for an 80-min sample of data from an 8-element array of microbarographs detects the presence of a signal from a high energy event despite a signal-to-noise ratio of less than unity. Co-phase analysis of acoustic signals generated by the Saturn-Apollo rocket launches indicates that these signals originate at ionospheric heights and propagate in a waveguide between a sound speed maximum and a steep density gradient in the mesosphere.

E. Smart and E.A. Flinn, "**Fast Frequency-Wavenumber Analysis and Fisher Signal Detection in Real-Time Infrasonic Array Data Processing,**" Geophys. J.R. astr. Soc. 26, 279 (1971).

Abstract: A high speed algorithm for computation of frequency-wavenumber (f-k) spectra is developed, and two real-time infrasonic data processing techniques that it makes possible, are described: (1) Signal detection by search of f-k space. This process is

compared to the N-4 correlator, a broad-band signal detector. The f-k search with a Fisher detector has a theoretical advantage, which we verify in practice. (2) and f-k filter technique for calculating 'best beam' estimates. This technique traces the beam containing the maximum power, from frequency to frequency through f-k space, and thus allows for wandering of signal velocity and arrival azimuth. This maximum power function is taken as the frequency spectrum of the best beam. In our programs the Fisher statistic of the signal estimate, and the velocity and azimuth, are computed and displayed as functions of frequency. Examples from real data for both processing techniques are discussed.

J.F. Claerbout and A.G. Johnson, **"Extrapolation of Time-Dependent Waveforms along their Path of Propagation,"** Geophys. J.R. astr. Soc. 26, 285 (1971).

Abstract: Time-dependent waveforms are commonly extrapolated in space by means of rays and occasionally by means of diffraction integrals. It is possible to extrapolate time-dependent waves in space with a partial differential equation derived from the wave equation. There are stable numerical approximations. An example illustrates a mechanism for 'signal-generated noise' which is consistent with observations.

I. Tolstoy and J. Lau, **"Generation of Long Internal Gravity Waves in Waveguides by Rising Buoyant Air Masses and Other Sources,"** Geophys. J.R. astr. Soc. 26, 295 (1971).

Abstract: The displacement fields generated in an internal gravity wave waveguide between plane rigid walls are compared for two types of source: an explosive point source and a rising buoyant sphere moving at constant speed. It is concluded that for large enough spheres and comparable energy expenditures, the buoyant sphere is a far more efficient source of long internal gravity waves. In particular it appears possible to conclude that, in the case of large events such as nuclear or volcanic explosions in the atmosphere, the rising heated air mass can generate long wavelength (λ>500 km) internal gravity waves at ionospheric heights.

J.E. Thomas and L.B. Craine, **"Acoustic-Gravity Wave Propagation in a Measured Atmosphere,"** Geophys. J.R. astr. Soc. 26, 311 (1971).

Abstract: An atmosphere is modelled by averaging measurements taken at eight locations for 1968 September 9. The effectiveness of the modelling is evaluated by comparing the atmospheric dispersion properties determined from an experimentally recorded signal resulting from a nuclear explosion on that date and those computed from the model atmosphere. The effects of atmospheric winds are shown to change the dispersion properties.

A theoretical barogram is synthesized for a receiver located 7930 km from the source and is compared to the recorded signal for the event. Barograms are synthesized for two different source functions and the source functions are discussed.

R.J. Greenfield and D.G. Harkrider, **"Acoustic-Gravity Wave Calculations in a Layer with a Linear Temperature Variation,"** Geophys. J.R. astr. Soc. 26, 323 (1971).

Abstract: An exact expression is obtained for the acoustic-gravity layer matrix for an atmospheric layer having a linear temperature variation. Expressions are also derived for the layer derivative matrices needed to calculate group velocity and mode excitation. The method requires the evaluation of confluent hypergeometric functions, whose series representations are rapidly convergent for layers, such as the lower thermosphere, which have large temperature gradients. The procedure allows rapid accurate calculations in studies of acoustic gravity wave propagation. The new procedure is used to calculate phase and group velocities for the GR_0 mode at periods between 5 and 12 min and gives a change in these velocities of 0.3 per cent as compared with Press and Harkrider's results.

A.D. Pierce and J.W. Posey, **"Theory of the Excitation and Propagation of Lamb's Atmospheric Edge Mode from Nuclear Explosions,"** Geophys. J.R. astr. Soc. 26, 341 (1971).

Abstract: A relatively simple theoretical model of near-surface pressure pulse propagation from nuclear explosions is developed from the hypothesis that the early portion of the pulse travels in the real atmosphere's counterpart of Lamb's edge mode. Various concepts of geometrical acoustics are used in the construction of the model. The pulse travels along horizontal ray paths which may be refracted by horizontal variations in the height-averaged effective sound speed and wind velocity. The dispersion of the pulse as it propagates along such paths is governed by a one-dimensional wave equation similar to that derived by Korteweg & de Vries in 1895. Coefficients are found by comparison with the dispersion relation derived by Garrett in 1969 as an expansion in terms of a parameter ε describing deviations of the atmospheric profile from isothermal. The method of incorporation of terms governing accumulative far-field non-linear effects is indicated. Height variations in propagating variables are approximated to zeroth order in ε. Variations along horizontal ray paths are governed by the principle of conservation of modal wave action. The excitation of the edge mode is found by matching the general form of the far-field quasi-geometrical solution to the near-field solution for a point energy source in an isothermal atmosphere. Explicit expressions are given for the far-field pressure disturbance. Computations agree favorably with those based on a multimode theory for the first few cycles of the waveform. The edge mode theory leads to a number of implications, which may be compared with existing data. These include the prediction that the energy of the explosion yield may be estimated from a knowledge of the first peak-to-peak period and first peak-to-trough pressure amplitude in far-field records with very little information concerning atmospheric structure, and the prediction that anomalous azimuthal variations in waveform amplitudes may be cause by focusing or defocusing of horizontal ray paths for the edge mode.

S.L. Kahalas and B.L. Murphy, **"Acoustic-Gravity Wave Generation at 120 km Altitude by Sea Level Detonation: A Preliminary Analysis of the Greene-Whitaker Calculation,"** Geophys. J.R. astr. Soc. 26, 391 (1971).

Abstract: The Greene and Whitaker mechanism for the production of an acoustic-gravity wave in the 100-km region of the ionosphere is discussed from a physical point of view. The shock wave from a low altitude detonation propagates upward and, interacting with the atmosphere in the 100-km region, produces a horizontally propagating acoustic-gravity wave. Several aspects of this phenomenon are discussed. The initial period of the generated waves is in the 200-300 s range, the energy associated with the wave is about 0.3 per cent of the yield, and the wave generated appears to result principally from the refraction of the shock at the 100-km level.

S.L. Kahalas and B.L. Murphy, "**Second-Order Correction to the Reed-Otterman Theory,**" Geophys. J.R. astr. Soc. 26, 379 (1971).

Abstract: The theory of Reed and Otterman, which describes the propagation of a weak shock wave in an inhomogeneous medium, is extended to include the next higher-order term of relative overpressure. This extension allows a matching of theory to initial starting conditions of the shock at a point closer to the source that the Reed-Otterman theory itself. The modified theory gives a value of the shock pressure that agrees well with the numerical calculation performed by Greene and Whitaker for the upward moving shock wave from a low altitude detonation.

J.E. Thomas, A.D. Pierce, E.A. Flinn and L.B. Craine, "**Bibliography on Infrasonic Waves,**" Geophys. J.R. astr. Soc. 26, 399 (1971).

Abstract: The following bibliography is current through 1970 and is composed of references related to the generation, propagation and detection of sound radiation at ground level and at ionospheric heights. The frequency range of the pressure signals considered here encompasses those normally associated with acoustic, infrasonic, acoustic-gravity and gravity waves.

As an aid in locating references the material has been broken into a number of subject categories which are given below. Each entry is listed only under the subject that is considered to be the primary topic of the paper.

Subject category

I. Papers related to the design and description of instrumentation and to the analysis of data.

II. Papers in which the primary topic is the source mechanism for the generation of acoustic, infrasonic, acoustic-gravity, and gravity waves.

III. Papers related to the measurement, observation, and theory of ionospheric waves.

IV. Ground-level observations of pressure waves.

V. Theoretical papers on atmospheric pressure waves.

A.D. Pierce, J.W. Posey and E.F. Iliff, "**Variation of Nuclear Explosion Generated Acoustic-Gravity Wave Forms with Burst Height and with Energy Yield,**" J. Geophys. Res. 76, 5025 (1971). [July]

Abstract: A formulation of a method for synthesizing theoretical infrasonic far-field pressure wave forms generated by nuclear explosions is described which differs from that described by Harkrider in 1964 primarily in the method by which the source presence is incorporated. The rationale of the model is described and a number of predicted wave forms created by the detonation of nuclear explosions in temperature-stratified and wind-stratified atmospheres are presented to illustrate the effects of winds and the effect of the varying energy yield and of the height of the burst. Theoretical wave forms are compared with a number of observed wave forms previously exhibited by Harkrider. Discrepancies are pointed out among the predictions of Scorer, of Weston, of Hunt, Palmer, and Penney, and of Harkrider as to the effects of height of burst. Our formulation predicts the early portion of wave forms received on the ground to be nearly proportional to yield and it increase slowly with height of burst up to a height of the order of 40 km (which depends on yield) and then to decrease rapidly with further increasing height. These predictions are

explained in simpler terms it the early portion of the wave form is assumed to be carried in a single composite guided mode analogous to that predicted by Lamb for the isothermal atmosphere.

L. Liszka and S. Olsson, **"On the generation and detection of artificial atmospheric waves,"** J. Atm. Terr. Phys. 33, 1933 (1971).

Abstract: Preliminary results of detection of atmospheric waves produced by focusing of shocks generated by supersonic aircraft are presented. The flight trajectories were chosen so that the acoustic gravity waves following the shock front were focused on the ground after reflection from the stratosphere, or in the E-layer. Infra-acoustic waves were detected on the ground using a 2-Hz infra-acoustic interferometer-correlator. At the E-layer, the waves were detected using a modified vertical sounding technique. Results obtained during 11 test flights have shown that the ray tracing technique may be successfully used for predicting the propagation of atmospheric waves following shock fronts.

H. Mack and E. Smart, **"Frequency Domain Processing of Digital Microbarograph Array Data,"** J. Geophys. Res. 77, 488 (1972). [January]

Abstract: In this brief note we describe two frequency-domain processes suitable for signal detection and analysis of digital microbarograph array data. The processes are time varying spectral estimation (sonograms) and estimation of frequency-wave-number spectra. When used together these processes can yield estimates of spectrum, phase velocity, group velocity, signal arrival azimuth, modal composition of signals, and multipath effects. We show examples of these processes applied to records from the large aperture microbarograph array in Montana.

W.L. Donn and D. Rind, **"Microbaroms and the Temperature and Wind of the Upper Atmosphere,"** J. Atmos. Sci. 29, 156 (1972). [January]

Abstract: Microbaroms are regular pressure variations of a few microbars (dyn cm^{-2}) produced by the passage of infrasound (~5 sec period) radiated from ocean waves. Their amplitudes show prominent diurnal, semidiurnal and seasonal variations that are shown to depend on the presence or absence of one or two atmospheric sound ducts between the surface and an elevation of ~120 km. These ducts depend on the vertical temperature and wind structure of the atmosphere. For our station (Palisades, N.Y.), ducting of sound from the most common source of microbaroms (Atlantic Ocean storms) requires the presence of strong easterly winds at some upper reflection level. Variations (such as tidal) in these winds, as derived from available reports, are shown to account for the observed patterns of microbaroms. In particular, these patterns are shown to be controlled by effects of tidal and seasonal wind variations and stratospheric warmings. Having established the dependence of microbaroms on upper temperature and winds, we use the relationship to interpret these upper atmospheric conditions. Finally, we suggest that use of an expanded "synoptic" network of infrasound recorders would provide a simple procedure to monitor conditions in the upper atmosphere.

B.L. Murphy, **"Variation of Rayleigh-Wave Amplitude with Yield and Height of Burst for Intermediate-Altitude Nuclear Detonations,"** J. Geophys. Res. 77, 808 (1972). [February]

Abstract: The source strength for far-field Rayleigh-wave excitation is calculated as a function of yield height of burst for intermediate-altitude nuclear detonations (height of burst approximately 20-100 km). In general the source strength, and hence the far-field Rayleigh-wave amplitude, has a maximum (for a given yield) at a particular burst height. The altitude at which the maximum occurs depends on the detonation yield and on the Rayleigh-wave period under consideration. The maximum is more pronounced for the longer Rayleigh-wave periods. For intermediate-altitude detonations, the variation of fair-field Rayleigh-wave amplitude with yield is found to lie between the 1/2 and the 2/3 power of the yield, depending on the burst altitude and on the Rayleigh-wave period being considered.

A. Ben-Menahem, **"Mercury Tiltmeter as an Infrasonic Detector: Theory, Observations, and Applications,"** J. Geophys. Res. 77, 818 (1972). [February]

Abstract: Observations of acoustic gravity waves at Eilat by a mercury tiltmeter are reported and interpreted. Waves belonging to the first gravity mode (GR_0) and three acoustic modes (S_0, S_1, S_2) that originated at the Chinese nuclear air blast of October 14, 1970, were simultaneously recorded on infrasonic microbarographs and the newly installed MIT (Massachusetts Institute of Technology) tiltmeters. The explosion (yield, about 5 Mt) produced at a distance of 5024 km a surface overpressure of about 300μb at 240 sec. This overpressure in turn caused a horizontal displacement of 3μ and a tilt of $3x10^{-10}$ rad at the same period. Plane-wave theory is used to show that the incident sound wave can excite a surface wave at the recording site through a second-order coupling effect. The induced waves propagate in the earth with the sound phase velocity and decay exponentially with depth. This theory is in good agreement with the observations. It is shown that the surface sound pressure and the induced ground motion are tied by a simple relation from which the mean rigidity of the upper crust at the recording site can be derived. The local rigidity of the granitic upper crust at Eilat is thus found to be $3.22x10^{11}$ dynes/cm^2. Sensitivity of the tiltmeter to infrasonic waves in the period range 20-400 sec is estimated to be 10^{-12} rad/μb at zero site noise and electronic snr ratio of 1:1, with a detectability threshold at about 20 μb.

A.R. Jordan, **"Atmospheric Gravity Waves from Winds and Storms,"** J. Atmos. Sci. 29, 445 (1972). [April]

Abstract: Atmospheric gravity waves were explored on the leeward side of the north-south trending Continental Divide in Colorado by using an array of electronic microbarographs and recording anemometers. Observations of low-velocity gravity waves in a two-to-three octave region for wave periods of 3-24 min were made. These waves are apparently caused by locally generated signals from upper tropospheric winds, jet streams, weather fronts, thunderstorms, and severe weather, with shear the principal mechanism. Lee waves and moderate-to-severe turbulence were frequently observed in conjunction with the appearance of gravity waves generated at mountain-top level. A unique wave source is identified due to the interaction of down-slope winds on the leeward side of a mountain and an inversion-layer boundary. Weather fronts on some occasions seem to provide a passive boundary layer for the production of waves, but in other cases they may actively generate waves. Readings on summer thunderstorms indicate that an early arrival in the gravity-wave train is an exponential pressure pulse, or gust, resulting from a downward-

accelerating air parcel within the storm cell as it reaches maturity. An anemometer was found to be an essential companion tool to the microbarograph for a full understanding of the wave phenomena. Detailed weather information from the Denver station of the Natural Weather Service near the recording sites was used to supplement the basic data.

T.M. Georges and J.M. Young, "**Chapter 21 Passive Sensing of Natural Acoustic-Gravity waves at the Earth's Surface,**" in Remote Sensing of the Troposphere, V.E. Derr, Ed., U.S. Govt. Printing Office, (1972).

Abstract: A tutorial account is given of efforts to observe and interpret natural acoustic-gravity waves in the atmosphere. Emphasis is on how the waves are passively detected and analyzed, the kinds of wave phenomena that are actually observed, and what is now known (and what remains unknown) about other sensing techniques promise new insight into the role of waves in atmospheric dynamics.

C.A. Newton, "**Rayleigh Wave and Acoustic-Gravity Wave Signals from Nuclear Explosions in the Atmosphere,**" Teledyne Geotech (Alexandria Laboratories) Final Report: AFOSR-TR-72-2011, August 31, (1972). NTIS Number ADA750541.

Abstract: The detection of nuclear explosions in the atmosphere has posed problems to the variety of techniques used to sense the resulting disturbances. Hence, the research covered by the subject contract was directed toward the extraction of intelligence from microbarographic signals. The principal objective was to improve the ability to determine the yield and height of burst of nuclear explosions in the atmosphere. Necessarily there were two related, intermediate objectives: namely, to develop digital data processing techniques for detecting and analyzing signals recorded by microbarograph arrays, and to improve predictions of spectra and waveforms of acoustic-gravity waves as well as of their associated seismic surface waves. [Descriptors: nuclear explosions; detection; atmosphere models; airburst; height finding; intensity; microbarometric waves; Rayleigh waves; programming(computers); spectrum analyzers. Identifiers: acoustic gravity waves; NTISAF.]

R.K. Cook, "**Sound Waves in the Atmosphere at Infrasonic Frequencies,**" J. Acoust. Soc. Am. 51(A), 136 (1972). [October]

Abstract: Various geophysical processes generate sound waves in the atmosphere. Some typical sources are auroral discharges in the upper atmosphere, tornadoes and severe storms, surface waves on the oceans, volcanic explosions, earthquakes, and atmospheric oscillations arising from unstable wind flow at the tropopause. Man-made sources include powerful explosions and shock waves from vehicles moving at supersonic speeds, at altitudes below about 125 km. The components of sound-wave energy at infrasonic frequencies (oscillation periods > 1.0 sec) are propagated for large distances (thousands of kilometers) over the earth's surface with very little loss of energy from absorption by viscosity and heat conduction. But the propagation depends strongly on (a) the horizontally stratified temperature structure of the atmosphere, (b) the influence of gravity at oscillation periods greater than the atmospheric resonance period = 300 sec and (c) the nonuniform distribution of atmospheric winds. The microphones and electroacoustical apparatus at an infrasonics observation station, e.g., the one at Washington, D.C., measure (1) the amplitude and waveform of incident sound pressure, (2) the direction of local propagation of the wave, (3) the horizontal trace velocity, and (4) the distribution of sound wave energy

at various oscillation frequencies. Researches on propagation require observational data from a network of stations separated geographically at large distances, coupled with theoretical analysis of sound propagation, to arrive at useful results on the acoustics of the atmosphere.

W.L. Donn and N.K. Balachandran, "**Atmospheric Infrasound, 10 to 0.1 Hz,**" J. Acoust. Soc. Am. 51(A), 136 (1972). [October]

Abstract: Two tripartite arrays of capacitor microphones operating continuously in 10 to 1 and 1 to 0.1 Hz passbands are maintained at Lamont. Natural infrasound (about 0.2Hz) which is radiated by ocean waves is multiply reflected between the surface and the 100-km level in winter, and the 50-km level in the summer atmosphere. Periodic diurnal variations in amplitudes is shown to be related to the rotation of high velocity tidal winds in the upper atmosphere. Seasonal variations are shown to be controlled primarily by stratospheric winds (about 50-km elevation). Natural infrasound of about 6 Hz, detected over an interval of several years, is more common in winter but the source is not yet resolved. Infrasound from large rockets launched at Cape Kennedy is shown to be generated aerodynamically by the ascending and descending first stage booster at speeds greater than Mach 1. Frequencies observed at long range are from 2 to 0.1 Hz. The seasonal variations in rocket infrasound from maximum in winter to nearly nil in summer are controlled by variations in the stratospheric sound channel caused by variations in stratospheric winds from westerly in winter to easterly ins summer. Infrasonic waves are shown to generate seismic waves in low-velocity sediments by means of resonant coupling. Shock waves generated by Apollo rockets when passing at orbital elevations have been detected with great clarity on Bermuda and have been shown to generate seismic waves in the ground. Propagation details of both natural and artificial sound are determined by the application of three-component ray tracing.

E. Smart and E.A. Flynn, "**Digital Processing of Microbaragraph Array Data,**" J. Acoust. Soc. Am. 51(A), 136 (1972). [October]

Abstract: This is a review of recent developments in techniques for the detection and analysis of infrasonic signals recorded by arrays of microbarogrphs. We describe a high-speed algorithm for the calculation of frequency-wavenumber spectra, and discuss two data processing methods the new algorithm makes possible to carry out in real-time: first, signal detection by searching for maxima of power in frequency-wavenumber space, together with estimation of the significance of such maxima using a Fisher statistic [Alexandria Laboratories, SDL. Rep. 263]. This estimation procedure is compared to the classical broadband N-4 correlator detection algorithm, and shown to be superior in several ways. Second, we discuss a signal spectral estimation algorithm in which the signal power spectrum, phase velocity, azimuth of arrival, and Fisher statistic are calculated and displayed as functions of frequency; the estimates are constructed by tracing power maxima through frequency-wavenumber space, frequency by frequency. Time-domain waveform estimates using this "best-beam" technique are subject to considerably less error and distortion than the conventional procedure, which uses a constant phase velocity. Examples of these algorithms are shown using data from the large aperture microbarograph array in Montana.

W.C. Meecham, "**Generation of Infrasound by Atmospheric Turbulence,**" J. Acoust. Soc. Am. 51(A), 136 (1972). [October]

Abstract: Consider infrasonic atmospheric pressure variations, defined for our purposes to be in the period range from a few seconds to a few minutes. Such pressure fluctuations could come from nonpropagating pressure effects associated, for example, with the jet stream; such pressure variations are estimated. We shall be interested primarily in *propagating* pressure effects caused by atmospheric turbulence. Following standard aerosonic theory, which will be briefly reviewed, the intensity of low-frequency aerodynamic sound produced by upper atmosphere wind is estimated. The estimated power radiated by such aerodynamic sources is approximately that observed in noise measurements on the ground and in balloons. The infrasonic signals expected from large storms and from tornadoes will also be estimated and compared where possible with measurements. Certain characteristics of clear air turbulence could probably be sensed by arrays on the ground and this question will be briefly discussed. The possibility of sensing clear air turbulence in this way from moving aircraft will be examined.

J.M. Young, G.E. Greene and L.B. Craine, **"Infrasound Radiation from Severe Storms,"** J. Acoust. Soc. Am. 51(A), 136 (1972). [October]

Abstract: A review of experimental evidence over the last two decades leads to the conclusion that 1 to 100 MW of low-frequency acoustic energy is radiated from the immediate neighborhood of many severe meteorological storms. The most convincing evidence is from simultaneous observations of space-time correlated pressure fluctuations on widely separated microphone arrays in the United States, together with National Weather Service meteorological data on the occurrence of mid-continent storms. Presence of sound in the ionosphere above some of the same storms has been inferred from Doppler phase fluctuations where the ionospheric reflection points are located above the storm area. A broad frequency spectrum with periods from a few seconds to a few minutes has been found, and asymmetric propagation is probably due to stratospheric winds. Direction and directional changes of sound from nearby thunderstorms, together with weather radar results, indicate that funnels, tornadoes and hail need not be present but that the radiation occurs from very high clouds that often penetrate the tropopause. The radiating mechanism from these storm systems is not yet completely understood.

C.R. Wilson, **"Aurorally Generated Infrasonic Waves,"** J. Acoust. Soc. Am. 51(A), 136 (1972). [October]

Abstract: None.

I. Dalins, V.M. McCarty, G. Kaschak and W.L. Donn, **"Investigations of Acoustic-Seismic Effects at Long Range: Early Arriving Seismic Waves from Apollo 16,"** Lamont-Doherty Geological Observatory Technical Report No: ARO-12286.5-GS, November 29, (1972). NTIS Number: ADA095619/3/HDM.

Abstract: None. Descriptors: Seismic waves, resonance, acoustic waves, infrasonic radiation, long range (distance), seismic detection, launching, manned spacecraft, Florida, interference, wind direction, ocean waves, reprints.

I. Tolstoy, **"Infrasonic Fluctuation Spectra in the Atmosphere,"** Geophys. J.R. astr. Soc. 34, 343 (1973).

Abstract: The concept of normal co-ordinates furnishes a convenient and powerful method for calculating fluctuation spectra in linear media. The procedure is illustrated by two examples from atmospheric infrasonics, in which it is assumed that random forces set up fields of subsonic gravity waves in stratified fluids. The first example, a model of convective generation of waves by upward moving thermals, predicts power spectra of the type and magnitude that have been observed, in the 5 min to 1 hr bandpass, at times of strong convection. The second example discusses the generation of waves in the same bandpass by a horizontally moving fluid of random vertical forces, and may be viewed as a rough model of the effect of a turbulent layer in a tropospheric wind system; after introduction of critical layer effect the calculations can be made to agree with measurements of jet stream generated pressures at ground level. In both examples it is confirmed that the local value of the Vaisala frequency N plays a decisive role in shaping the spectrum; in the convective case it determines a peak frequency $\omega_0 < N$ by the influence of the input spectrum (i.e., the properties of the random force field); in the turbulent layer model, it actually determines rather well the frequency of a quite generally observed break in the spectrum curve although, here again, this break occurs at frequencies somewhat less than N.

F.H. Grover, **"Geophysical Effects of Concorde Sonic Boom,"** Q. Jl. R. astr, Soc. 14, 141 (1973).

Abstract: None.

H.S. Ribner, P.J. Morris and W.H. Chu, **"Laboratory simulation of development of superbooms by atmospheric turbulence,"** J. Acoust. Soc. Am. 53, 926 (1973). [March]

Abstract: A jet flow was used to model roughly a localized region of atmospheric turbulence, simulating a single idealized "eddy". The jet was arranged in the UTIAS 80-ft sonic-boom generator horn so as to blow either against or with the direction of boom propagation. The two cases produced spiked and rounded boom signatures, respectively, qualitatively in accord with theory. The resemblance to signatures resulting from supersonic flight under turbulent atmospheric conditions was especially marked with the spiked "superbooms."

A.U. Kerr, P.F. Skefington, E.A. Flinn and E. Smart, **"Digital Analysis of Microbarograph Data,"** Teledyne Geotech (Alexandria Laboratories) Technical Report AL-72-6 (AFOSR-TR-73-0862, March 9, (1973). NTIS Number: ADA760769.

Abstract: The results of analysis of microbarograph records from two presumed atmospheric nuclear explosions are given. The events occurred on 27 December 1968 and 29 September 1969, and were recorded by microbarograph arrays in Boulder, Colorado, College, Alaska, Huancayo, Peru, Tel Aviv, Israel and at LAMA, the Large Aperture Microbarograph Array in Montana. The authors also show LAMA data and analysis results for eight other presumed explosions. In addition to demonstrating the effectiveness of the digital detector, the purpose of the report is to make the calibrated data and spectral calculations available to other workers in this field. [Descriptors: nuclear explosions; microbarometric waves ; microbarometric waves; spectrum analyzers; digital recording systems; power spectra; airburst. Identifiers: Large aperture microbarograph arrays; signal processing; infrasonic radiation; NTISAF]

A.D. Pierce, C.A. Moo and J.W. Posey, **"Generation and Propagation of Infrasonic Waves,"** Massachusetts Institute of Technology Technical Report No: AFCRL-TR-73-0135, April 30 (1973). NTIS Number ADA766472/5.

Abstract: A review is given of theoretical studies on infrasound generation and propagation through the atmosphere which were carried out under the contract. These studies include (1) further development and application of a computer program for the prediction of pressure signatures at large distances from nuclear explosions, (2) development of an alternative approximate model for waveform synthesis based on Lamb's edge mode, (3) development of a geometrical acoustics' theory incorporating nonlinear effects, dispersion, and wave distortion at caustics, and (4) a theoretical model for the prediction of acoustic gravity wave generation by rising and oscillating fireballs. Numerical studies are reviewed which indicate the dependence of far field waveforms on energy yield and burst height. Implications of the Lamb edge mode theory include a new method for estimating energy yield from waveforms and an explanation of amplitude anomalies in terms of focusing or defocusing of horizontal ray paths. [Descriptors: microbarometric waves; atmosphere models ; sources; nuclear explosions; storms; wave transmission; mathematical models; programming (computers). Identifiers: gravity waves; acoustic gravity waves; infrasonic waves; computer program; NTISAF.]

S.H. Francis, **"Acoustic-Gravity Modes and Large-Scale Traveling Ionospheric Disturbances of a Realistic, Dissipative Atmosphere,"** J. Geophys. Res. 78, 2278 (1973). [May 1]

Abstract: The guided acoustic-gravity modes that can propagate in a realistic dissipative atmosphere are computed for periods between 30 sec and 2 hours. The analysis differs from previous treatments by including dissipation (viscosity and thermal conductivity) and by using a realistic sound speed profile throughout the thermosphere. The presence of realistic dissipation allows a unique determination of the acoustic-gravity mode spectrum free from ambiguities related to the choice of the upper boundary condition. Since the atmospheric model below the thermosphere is similar to those used in previous studies, the characteristics of the lower atmospheric modes (e.g., the Lamb mode) are essentially unchanged from previous analyses of fully ducted modes in dissipationless atmospheres. The attenuation distances of these lower atmospheric modes, defined as the distances required for the modes to be attenuated by a factor of 1/e, are of the order of the earth's circumference or greater. The upper atmospheric modes, on the other hand, exhibit several characteristics that disagree with the results of previous analyses. The calculations reported here reveal the existence of several long-period modes with average speeds between 300 and 700 m/s, all composed at F region heights of internal gravity waves with nearly horizontal phase fronts. Their attenuation distances are of the order of 1/8 of the way around the earth or less. All the properties of these upper atmospheric modes agree qualitatively with the observed characteristics of large-scale F region traveling disturbances (TID's). Ion drag is not found to be particularly important, but changes of thermospheric temperature due to diurnal and solar cycle variations are found to have quite appreciable effects on the upper atmospheric modes.

A.D. Pierce, **"Theory of Infrasound Generated by Explosions,"** Colloque International sur les Infra-Sons, Proceedings (Centre National de la Recherche Scientifique (CNRS) 15, quai Anotole France, 75700 Paris, September (1973). [September]

Abstract: A review is given of recent studies by the author and his colleagues on infrasound generation by explosions and the subsequent propagation through the atmosphere. These studies include (i) development of computer programs for the prediction of pressure signatures at large distances from nuclear explosions, (ii) development of an alternative approximate model for waveform synthesis based on Lamb's edge mode, (iii) development of a geometrical acoustics' theory incorporating nonlinear effects, dispersion, and wave distortion at caustics, and (iv) theoretical models for the mechanisms of wave generation by explosions. The basic theory is briefly outlined in each case and some of the more significant results are explained in terms of simplified models. Such results include the predicted dependence of far field waveforms on energy yield and burst height, suggested techniques for estimating energy yield from waveforms, and an explanation of amplitude anomalies in terms of focusing and defocusing of horizontal ray paths.

J.W. Reed, "**A Climatology of Distant Air Blast Propagation,**" J. Acoust. Soc. Am. 53(A), 340 (1973). [November]

Abstract: Microbarograph data from Nevada atmospheric nuclear tests of 1951-1962 and some recent large chemical explosives tests are presented to show climatological patterns for long range propagation to about 225 km. Amplitudes are normalized to 1-kiloton yield, free airburst, and corrected for height-of-burst effects. Propagations under early morning temperature inversions often showed double the amplitudes expected for standard hemispherical explosion wave expansion at 30-km ranges. Strong upper winds, at 6- 10-km altitudes, occasionally gave as much as 5x magnification at 50-150 km. Ducting by the high stratosphere, near 50-km altitude, is seasonally directed eastward in winter, westward in summer. Amplitudes in the sound ring, near 225-km range show as much as 3x magnification downwind and 0.006x reduction upwind. [Sandia Lab Paper]

E.S. Posmentier, "**Infrasound of 1 through 16 Hz Associated with Clear Air Turbulence,**" J. Acoust. Soc. Am. 53(A), 372 (1973). [November]

Abstract: 1- through 16-Hz infrasound detected by a four-element array of microphones was recorded six times daily from April through June 1971. Four records were selected as representative of extremely low-amplitude conditions. Four other records were chosen as representative of highly coherent, strong-amplitude records. These latter four records all exhibited very high horizontal phase speeds, implying near-vertical incidence. A search was made for meteorological parameters which varied consistently with the acoustic data. It has been found that all four low-amplitude records were from periods during which nonturbulent conditions probably existed between altitudes of 6 and 12 km. The four strong-amplitude records coincide with times of high probability of clear air turbulence. The turbulence judgments are based on the wind speed, the directional shear, and Richardson's number, calculated from nearby radiosonde data. It is concluded that 1- through 16-Hz infrasound may be radiated by clear air turbulence, and may be a basis for a remote passive detection system. If confirmed, this conclusion would have significant implications for both practical and theoretical problems associated with clear air turbulence.

T.M. Georges, "**Infrasound from Convective Storms,**" Rev. Geophys. Space Phys. 11, 571 (1973).

Abstract: Two kinds of waves, infrasonic pressure fluctuations recorded on the ground and certain wavelike fluctuations in ionospheric phase height recorded by ground-based radio sounders, have been independently associated with some severe convective storms.

When we compare their phenomenologies, such a remarkable similarity emerges that it is hard to avoid the conclusion that both waves are different manifestations, in different parts of the acoustic spectrum, of the same emission mechanism. We tabulate the constraints each observation imposes on possible source models and estimate the average acoustic power required. A case study of one storm observed with both techniques reinforces the hypothesis of a common emission mechanism.

T.M. Georges, **"Infrasound from Severe Storms,"** Eigth Conference on Severe Local Storms, AMS, Boston, MA, October 15-17, (1973).

J.W. Rockway, G.L. Hower, L.B. Craine and J.E. Thomas, **"Applications of Ray-Tracing to Observations of Mountain-Associated Infrasonic Waves,"** Geophys. J.R. astr. Soc. 36, 259 (1974).

Abstract: Previous studies have identified a class of infrasonic waves characterized by periods ranging from 10 to 100 seconds, horizontal trace velocities across the detecting array at acoustic velocities or greater, and zero to peak amplitudes from 0.5 to 7 dyne cm^{-2}. These signals triangulate principally in mountainous regions and have thus been termed mountain-associated waves. In this paper, the effects of propagation conditions on the observed characteristics are examined using a ray-tracing technique implemented on a hybrid computer. It is shown that the observed seasonal variation in occurrence of these waves follows from the conditions along the propagation path-primarily winds-and therefore may not be indicative of variations the actual generating mechanism.

W.A. Kinney, C.Y. Kapper and A.D. Pierce, **"Acoustic Gravity Wave Propagation Past the Antipode,"** J. Acoust. Soc. Am. 55, S75(A) (1974). [April]

Abstract: The previous theoretical formulations and numerical computations of pressure waveforms (such as described by Harkrider, Pierce, and Posey, and others) apply only to atmospheric traveling waves which have traveled less than 1/2 the distance around the earth. In the present paper, a technique resembling that previously introduced by Brune, Nafe and Alsop [Bull. Seismol. Soc. Am. 51, 247-257 (1961)] for elastic surface waves is discussed and applied to the acoustic gravity-wave propagation past the antipode problem.

The principal modification to the older theory is a shift in phase of $\pi/2$ to the Fourier transform of the wave after it has traveled over halfway round the globe from the source. The source of the wave is presumed to be a nuclear explosion of given energy E. Numerically synthesized waveforms of antipodal arrivals are exhibited and compared with those for direct arrivals. The necessary modifications to the Lamb mode model theory of Pierce and Posey [Geophys. J. Roy. Astron. Soc. 26, 341-368 (1971)] are also described.

K.C. Yeh and C.H. Liu, **"Acoustic-Gravity Waves in the Upper Atmosphere,"** Rev. of Geophysics and Space Physics, 12, 193 (1974). [May]

Abstract: In this paper we review the theory of acoustic-gravity waves, the interaction of such waves with the ionosphere, the experimental support for the existence of such waves in the upper atmosphere, and the role played by acoustic-gravity waves in an ideal isothermal atmosphere. After a thorough discussion on the properties of acoustic-gravity waves in an ideal isothermal atmosphere, the effects produced by horizontal winds, sharp boundary discontinuities, and dissipative processes are discussed. The generation of these

waves by stationary or moving sources is then treated. It is shown that the atmospheric response to a stationary impulse source can be described by the emission of three waves: acoustic, buoyancy and gravity. These discussions are then followed by reviewing propagation effects in a realistic atmosphere for both free and guided waves. Recent numerical results are given. When acoustic gravity waves propagate through the ionosphere, interaction between the wave and the ionosphere will take place. The physical processes involved in such an interaction between the wave and the ionosphere will take place. The physical processes involved in such an interaction are examined. The response of the ionosphere to acoustic-gravity waves can be fairly complex, but its understanding is necessary to interpret various experimental data. The existing experimental data on traveling disturbances are then reviewed. The existence of acoustic-gravity waves throughout the atmosphere implies coupling between the lower atmosphere and the upper atmosphere. Transport of both momentum and energy are accompanied by the wave process. The implication of momentum and energy transport on thermospheric dynamics is discussed.

R.K. Cook, **"Symposium on atmospheric acoustics and noise propagation,"** J. Acoust. Soc. Am. 55, 926 (1974). [May]

Forward and Introduction: A conspicuous feature of atmospheric acoustics is the great diversity of observed propagation phenomena, and the corresponding diversity of analytical frameworks required for description of the phenomena. On a large scale, the atmosphere is stratified in horizontal layers under the force of gravity. Therefore the local temperatures and densities, and *ipso facto* the sound velocity and the absorption cross section per unit volume, are strong functions of elevation above the earth's surface. The local acoustic absorption cross section, for example, increases by about six orders of magnitude between the surface and the region at 100-km elevation, near the lower edge of the ionosphere. Surface winds, temperature gradients, and turbulent motions strongly affect acoustical propagation at audible frequencies of oscillation. The atmospheric effects are in general nonstationary in time. The net results is that researches in atmospheric acoustics proceed on a series of seemingly independent technical fronts.

Recent advances in atmospheric acoustics were presented in about 50 papers at the Symposium held 27-29 September 1072 at the Gaithersburg, Maryland, laboratories of the National Bureau of Standards. The principle purpose was to bring together people working on the science of atmospheric sound for discussion of the present state of the art and its technical problems. The Bureau and the Acoustical Society of America cosponsored the event, with the cooperation of the International Commission on Acoustics.

The Program Committee arranged for eight invited papers, in the areas of acoustical remote sensing of the atmosphere, absorption and scattering, infrasound, acoustic-gravity waves, nonlinear waves, noise propagation, and sonic booms. There were about 40 contributed papers. Abstracts of all of the Symposium papers were published in this *Journal* [J. Acoust. Soc. Am. 52, 1309-1317 (1972)]. The six papers which follow in this issue, pp. 927-963, are the first group to be published.

In addition to the Symposium papers now being published, three recent publications have brought together comprehensive groups of papers on atmospheric acoustics:

(1) "Special Issue on Infrasonics and Atmospheric Acoustics," Geophys. J.R. Astron. Soc. 26, 1-425 (1971).

(2) "Sonic Boom Symposium," held at the 80th Meeting of the Acoustical Society, Houston, Texas, 3 November 1970; J. Acoust. Soc. Am. 51, 671-798 (1972).

(3) "Effects of Atmospheric Acoustic-Gravity Waves on Electromagnetic Wave Propagation, "AGARD Conference held at Wiesbaden, Germany, 17-21 April 1972, AGARD Conference Proceedings No. 115.

T.M. Georges and G.E. Greene, **"Infrasound from the 29-30 April 1970 Storms,"** in Papers on Oklahoma Thunderstorms, April 29-30, 1970, Edited by Stanley L. Barnes, NOAA Technical Memorandum ERL NSSL-69, pp. 185-193 May (1974). [May]

Abstract: We report the observable features of infrasound recorded at Boulder, Colorado, and San Diego, California, during the subject storm. Triangulation indicates that the emissions originated in north-central Texas, not in the Oklahoma City area.

H.S. Bowman, **"Frequency spectra information on storm-related infrasound,"** J. Acoust. Soc. Am. 55, 927 (1974). [May]

Abstract: Infrasonic data were collected and associated with various severe storms. The local and/or distant storm phenomena occurred in a variety of geographic locations having numerous terrain from orographical to plane. Acoustic spectral characteristics of some of the infrasonic signatures were studied in order to possibly assort the various storms. Preliminary results indicate an apparent procedure for classification via spectral analysis of infrasound propagation data.

D.A. Hilton and H.R. Henderson, **"Measurements of sonic-boom overpressure from Apollo space vehicles,"** J. Acoust. Soc. Am. 56, 323 (1974). [August]

Abstract: This paper presents representative results of sonic-boom overpressure data recorded during the launch and reentry of the Apollo 15 and 16 space vehicle systems. Comparisons are made between measured overpressures and those predicted using available theory. The measurements were obtained along the vehicle ground track at 68, 87, 92, 129, and 970 km downrange from the launch site during ascent, and at 9, 13, 55, 185, and 500 km from the splash-down point during reentry. Also included are tracings of the sonic-boom signatures along with a brief description of the launch and recovery test areas in which the measurements were obtained, the sonic-boom instrumentation deployment, flight profiles and operating conditions, and high-altitude weather information for the general measurement areas.

J.A. McDonald, **"Naturally occurring atmospheric acoustical signals,"** J. Acoust. Soc. Am. 56, 338 (1974). [August]

Abstract: Atmospheric disturbances located close to microbarograph arrays in north Texas are assumed to be caused by sources of acoustic-gravity waves and/or infrasound. The sources studied are large storms, hurricanes, tornadoes, and frontal systems. The large-amplitude long-period acoustic-gravity waves are readily found, but detection of infrasound presents problems which are indicated and some possible solutions are suggested.

J.W. Reed, **"Archiving Guide to Microbarograph Records of Nuclear and Chemical Explosion Tests,"** Sandia National Laboratory Technical Report SLA-74-0210, August (1974). [August]

Abstract: Microbarograph records of airblast waves, made at distances of 20 km to over 500 km from various nuclear test explosions (1953) through 1973) and from certain chemical high-explosives tests, have been placed in permanent archives. These records, which contain detailed information on airblast propagation that has never been completely evaluated and reported, are not amenable to current microstorage techniques and cannot be reproduced by future experimenters.

This report was prepared to guide future investigators to the archive storage boxes and filing system. Included are brief summaries of the test operations, projects, events, and purposes of microbarography, as well as a selected bibliography on Sandia microbarography and blast prediction operations.

I. Dalins, V.M. McCarty, G. Kaschak and W.L. Donn, **"Investigations of acoustic-seismic effects at long range: early-arriving seismic waves from Apollo 16,"** J. Acoust. Soc. Am. 56, 1361 (1974). [November]

Abstract: A reasonably comprehensive technical effort is described dealing with the investigations of acoustically generated seismic waves of Apollo 16 and Apollo 17 origin along the eastern seaboard of the United States. This expanded effort is a continuation of earlier, rather successful detections of rocket-generated seismic disturbances on Skidaway Island, Georgia. The more recent effort has yielded few positive results other than a recording of an early-arriving seismic wave from Apollo 16 that was detected in Jacksonville. Evaluation of the negative results obtained in the Fort Monmouth area, with earlier studies of infrasound, local weather conditions, and geology, could be advantageous in the process of trying to gain a better insight into the acoustic-seismic resonance mechanism requiring phase-velocity matching at the atmosphere-ground interface. The evaluation of the recording of early-arriving seismic disturbances in Jacksonville also yielded certain new information about this acoustic-seismic resonance phenomenon.

W.L. Donn, N.K. Balachandran and G. Kaschak, **"Atmospheric infrasound radiated by bridges,"** J. Acoust. Soc. Am. 56, 1367 (1974). [November]

Abstract: Constant-frequency infrasound (about 5 to Hz for different sources) has been detected at a number of locations from different directions. In an intensive study of 8.5 Hz infrasound detected regularly at Lamont-Doherty Geological Observatory of Columbia University in Palisades, N.Y., positive sound fixes have been obtained at the Tappan Zee Bridge. Geophones placed at several locations on the bridge recorded vibrations of the same frequency. We conclude that the infrasound is most readily detected during times when atmospheric wind and temperature structure favor acoustic channeling near the ground. The acoustic signal occurs in pulses having a duration which, although fairly constant on a given occurrence, may vary from a fraction of a minute to several minutes.

S.D. Gedzelman, **"Influence of rotation of the Kelvin-Helmholtz instability,"** J. Acoust. Soc. Am. 56, 1371 (1974). [November]

Abstract: A two-layer fluid which is inviscid and which has no conduction is considered. Once rotation is included in the perturbation equations, a cubic equation for the square of the wave speeds of two-dimensional waves results. Two of the roots can be closely approximated in rather simple analytic form. These roots are generally more unstable than the nonrotating waves. The root which is not degenerate as rotation approaches zero owes its greater instability under the presence of rotation to the fact that the fluid interface is tilted

with respect to the gravity vector and the stabilizing role of the stratification is thereby reduced.

L. Liszka, **"Long-distance propagation of infrasound from artificial sources,"** J. Acoust. Soc. Am. 56, 1383 (1974). [November]

Abstract: Infrasound from distant artificial sources has been detected at 2 Hz by a chain of stations in Sweden. A number of infrasound sources were located and identified as hydroelectric power plants, industrial plants, and oil fields. The infrasound from distant artificial sources propagates with reflections in the upper atmosphere: during summer mainly with reflections in the stratospheric sound channel and during winter with reflections in the upper sound channel.

J.E. Thomas, T.H. Kuckertzm J.D. Logan, T.K. Law and L.B. Craine, **"Possible source mechanisms for a frequently occurring infrasonic signal,"** J. Acoust. Soc. Am. 56, 1391 (1974). [November]

Abstract: Commonly occurring infrasonic waves recorded during the winter months are believed to originate by means of aerodynamic source mechanisms. Acoustic power spectra of these commonly observed signals are compared to the power spectra one would observe from theoretical source mechanisms. From this comparison, the theoretical source mechanism believed responsible for production of the observed signals is thought to be isotropic turbulence in the lee of mountain peaks. Experimentally recorded signals and their power spectra are shown. Source regions of three signals are identified.

C.Y. Kapper, **"Leaky Infrasonic Guided Waves in the Atmosphere,"** J. Acoust. Soc. Am. 56(A), S2 (1974). [November]

Abstract: Prior theoretical formulations and computational techniques for the prediction of pressure waveforms generated by large explosions in the atmosphere have considered only fully ducted modes. In the present paper, a technique for including weakly leaking guided modes in concert with fully ducted modes is developed. Modification of previous theory includes the extension of the boundary condition at the upper halfspace to include a complex horizontal wavenumber. The major alterations to the computer program Infrasonic Waveforms (as described in the report by Pierce and Posey, 1970) incurred consist of the computation of the imaginary part of the newly incorporated complex wavenumber, extension of the normal-mode dispersion function to lower frequencies, and a second-order correction factor to the phase velocity.

W.A. Kinney, **"Asymptotic High-Frequency Behavior of Guided Infrasonic Modes in the Atmosphere,"** J. Acoust. Soc. Am. 56(A), S2 (1974). [November]

Abstract: Refinement of previous theoretical formulations and numerical computations of pressure waveforms as applied to atmospheric traveling infrasonic waves could include a description of their asymptotic behavior at high frequencies. In the present paper, calculations based on the WKBJ approximation and similar to those introduced by Haskell [J. Appl. Phys. 22, 157 (1951).] are performed to describe the asymptotic behavior of infrasonic guided modes as generated by a nuclear explosion in the atmosphere. The results of these calculations are then matched onto numerical solutions which have been given by Harkrider, Pierce and Posey, and others. It is demonstrated that the use of these asymptotic

formulas in conjunction with a computer program which synthesizes infrasonic pressure waveforms has enabled the elimination of problems associated with high-frequency truncation of numerical integration over frequency. In this way, small spurious high-frequency oscillations in the computer solutions have been avoided.

C.Y. Kapper, **"Computational Techniques in Infrasound Waveform Synthesis,"** M.S. Thesis, School of Mechanical Engineering, Georgia Institute of Technology, December, (1974). [December]

Abstract: This thesis is concerned with two major theoretical and programming modifications to the digital computer program INFRASONIC WAVEFORMS for the synthesization of acoustic-gravity pressure waveforms generated by large explosions in the atmosphere. The first modification involves the extension of the guided mode approximation for pressure waveforms in the atmosphere into leaking mode regions and a consequent search for the imaginary part of the complex horizontal wave number. Particular results include a plot of phase velocity versus angular frequency showing the extension of the normal mode dispersion function into a leaky mode region for a multilayer atmosphere and a report on the search for the imaginary part of the complex horizontal wave number of a leaky mode for a two layer atmosphere. The second modification involves the extension of the synthesis of acoustic-gravity pressure waveforms to distances beyond the antipode. A phase shift is noted for waves passing through the antipode and a comparison of pre- and post-antipodal waveforms is presented.

D.O. Revelle and W.L. Donn, **"Meteor-Generated Infrasound,"** Lamont-Doherty Geological Observatory Technical Report No: LDGO-2199 (ARO-12286.7-GS), February (1975). NTIS Number: ADA095618/5/HDM. [February]

Abstract: None. Report published in Science, 189, 394 (1975). [August]

G.E. Greene and J. Howard, **"Natural Infrasound: A One Year Global Study,"** NOAA TR, ERL 317-WPL-37, March (1975). [March]

Abstract: Using continuous pressure records from eight infrasonic observatories around the world, we have compiled statistics on infrasound occurrence and on the background noise distribution that affects the detectability of infrasound. With triangulation, the source locations for over 200 infrasonic events have been established. The most frequently detected sources appear to lie in or near certain mountainous regions throughout the world.

R.K. Cook, **"Introductory remarks on arrays for measurement of complicated wave fields,"** J. Acoust. Soc. Am. 57, S8 (1975). [April]

Abstract: We examine methods for sorting out and measuring the distributions of strengths and propagation directions for the component waves in spatially complicated wave fields. Such measurements are needed in atmospheric and underwater sound, in seismology, and for electromagnetic microwaves. For example, the diffuseness of the sound field in a reverberation chamber needs to be measured and described in terms of its component plane waves. The distributions might not be stationary in time, particularly when moving vanes are employed. This measurement art seems to require the use of geometrical arrays of phased transducers. Quasiholographic techniques, such as beam formation and synthetic aperture, are used for comparison of the phases and time delays at

the various locations in the array. The distributions are then derived from the comparison and may be displayed with optical techniques. The invited papers of this session describe the present state of this difficult art.

J.M. Young and A.J. Bedard, Jr., "**Array design and processing techniques for study of atmospheric wave fields,**" J. Acoust. Soc. Am. 57, S8 (1975). [May]

Abstract: We distinguish between atmospheric acoustic and gravity waves, describe their characteristics, and discuss optimum array configurations for studying them in the presence of turbulent-pressure fluctuations. The separation of two or more waves present simultaneously-and the distinction between waves from point- and distributed sources in the presence of inhomogeneities and uniform variations in the medium-present problems that are only partially solved. We outline the application of both analog and digital array processing techniques to the determination of transient atmospheric pressure wave characteristics as a function of space and time. These techniques are applied to several examples of infrasonic signals and atmospheric gravity waves to illustrate the present state of processing. A review of recent improvements suggests to us that future work should be directed toward (1) optimum use of constraints imposed by wave dispersion, source mechanisms, etc., in order to arrive at conclusions more directly, and (2) optimum display of results to enhance recognition of qualitative and quantitative differences in the distribution of wave parameters corresponding to waves of different types.

L.B. Evans, "**Atmospheric absorption of sound: validity of two-relaxation -process model,**" J. Acoust. Soc. Am. 57, S17 (1975). [May]

Abstract: A comparison of the predictions of the generalized kinetic description and the simpler two-relaxation-process model for absorption of sound in air has been made [H.E. Bass, J.E. Piercy, L.B. Evans, and L.C. Sutherland, J. Acoust. Soc. Am. 56 S1(A) (1974); L.C. Sutherland, J.E. Piercy, H.E. Bass and L.B. Evans, J. Acoust. Soc. Am. 56, S1(A) (1974)]. The two models are compared over the temperature range of 0^{o}-40^{o}C and from 1% to 100% relative humidity. The agreement between the two models is found to be quite good in most cases, with some exceptions which are easily explained. A comparison is also made to available experimental data which shows the validity of the models.

J.S. Flores and A.J. Vega, "**Some relations between energy yield of atmospheric nuclear tests and generated infrasonic waves,**" J. Acoust. Soc. Am. 57, 1040 (1975). [May]

Abstract: The relation between energy yield in megatons (MT) of atmospheric tests during 1968-1971 at French Polynesia and infrasonic waves recorded at Penas in Bolivia (a distance of approximately 7300 km) is studied. Yields were estimated from period and amplitude of the early portion of the waveforms using the theoretical relation of Pierce and Posey [Geophys. J. R. astron Soc. 26, 341 (1971)]. In the present paper, the relation of this derived yield to the power spectrum of the major portions of the waveforms is investigated. The magnitude of the square root of this spectrum of major portions of the waveforms is investigated. The magnitude of the square root of this spectrum that can be considered proportional to the Fourier integral for a yield sample time (i.e., spectral amplitude) typically has two characteristic peaks, the first of which appears to be nearly directly proportional to yield, the proportionality constant being 300 μbar $sec^{1/2}$/MT.

Another waveform feature exhibiting strong correlation with yield is the time duration of the gravity wave train which precedes the acoustic mode waves. For smaller yields, this also appears to vary nearly linear with yield, the proportionality constant being 1000 sec/MT up to about 1 MT. The application of these conclusions to other source-receiver geometries and to other meteorological conditions remains a topic for future study.

D.O. ReVelle, **"Meteor-Generated Infrasound,"** Science 189, 394 (1975).
W.L. Donn and N.K. Balachandran, Science 189, 395 (1975). [August 1]

Abstract: None. Paper questions the *Donn and Balachandran's* (1974) linkage of meteors to infrasound. *Donn and Balachandran* Science 189, 395 (1975) respond defending the association of meteors and infrasound.

C.R. Wilson, **"Infrasonic wave generation by aurora,"** J. Atm. Terr. Physics 37, 973 (1975).

Abstract: A comparison of the characteristics of auroral infrasonic waves (AIW) in the passband from 10 to 100 sec. period is given for trans-auroral zone stations. The morphology of 2 Hz infrasound observed at Kiruna, Sweden is described. An important asymmetry in the generation of AIW bow waves, with respect to poleward or equatorward motion of auoral electroject arcs, is shown to be related to the morphology of the ionospheric E-region electric field during an auroral substorm. Auroral radar studies of AIW source arcs are presented Incoherent scatter radar observations of electron density profiles of auroral arcs are used to describe the differences in arcs that do or do not produce AIW in an attempt to explain the asymmetry in AIW generation by supersonic auroral arcs. An infinite line-current induction model of an auroral electrojet moving transverse to its axis above a conducting earth is used to determine the relationship of an AIW to the surface magnetic perturbation produced be the electrojet. The role of the auroral electrojet in AIW production is discussed in a study of polar magnetic substorms wherein westward traveling auroral surges and the eastern ends of westward auroral electrojets were found to be strong sources of AIW. Theoretical work on the generation of AIW's is reviewed and evaluated with respect to the observed characteristics of AIW substorms. Lorentz force and Joule heat are discussed as probable source terms for the production of the acoustic energy within an auroral electrojet. The important unsolved problems in understanding auroral infrasound are outlined.

S.H. Francis, **"Global propagation of atmospheric gravity waves: A review,"** J. Atm. Terr. Physics, 37, 1011 (1975).

Abstract: The theoretical and observational evidence concerning the global propagation of atmospheric gravity waves is reviewed, with special emphasis on waves generated in the auroral zones. Gravity-wave theory predicts that the response to an auroral source mechanism consists of a discrete spectrum of upper-atmospheric guided modes and a continuous spectrum of freely propagating internal waves.

W.A. Kinney, A.D. Pierce and C.Y. Kapper, **"Atmospheric Acoustic Gravity Modes Near and Below Low Frequency Cutoff Imposed by Upper Boundary Conditions,"** J. Acoust. Soc. Am. 59(A), S1 (1975). [November]

Abstract: Perturbation techniques are described for the computation of the imaginary part of the horizontal wavenumber (k_I) for modes of propagation. Numerical studies were carried out for a model atmosphere terminated by a constant sound-speed (478 m/s) half space above an altitude of 125 km. The GR_0 and GR_1 modes have lower-frequency cutoffs. It was found that for frequencies less than 0.0125 rad/sec, the GR_1 mode has complex phase velocity: K_I varying from near zero up to a maximum of 3 x 10^{-4} km^{-1} with analogous results for the GR_0 mode. There is an extremely small frequency gap for each mode for which no poles in the complex k plane corresponding to that mode exist. These mark the transition from undamped propagation to damped propagation. In the complete Fourier synthesis, branch line contributions compensate for the absence of poles in these gaps. Computational procedures are described which facilitate the inclusion of the low-frequency portions of these modes in the waveform synthesis.

T.M. Georges and G.E. Greene, **"Infrasound from Convective Storms. Part IV. Is It Useful for Storm Warning?,"** J. Appl. Meteorology 14, 1303 (1975). [November]

Abstract: An experiment was carried out to collect statistics on the observability of severe-storm infrasound at three stations during the 1973 storm season. The results have been evaluated with the help of four "indices of usefulness":

• *False-alarm rate,* which tells how often infrasound from other sources is mistaken for that from storms. We devised a sorting procedure that reduces the false-alarm rate to 15-20%, and still lower rates seem achievable.

• *Detection rate,* which tells what fraction of severe storms are detected. Here the big problems are defining what we mean by "severe storm" and verifying their occurrence; we estimate a 65% detection rate for tornadic storms, a 31% detection rate for tornadoes themselves, and a 33% detection rate for storms with radar tops above 50,000 ft.

• *Timeliness,* which tells how much advance warning the waves give compared to dangerous storm effects. It was practical to consider only tornadoes from this viewpoint, and we found that the emissions tend to precede tornado onset by an hour or so.

• *Location accuracy,* which tells how well the emissions can be used to locate and track storms. This index is hard to evaluate quantitatively, as illustrated by the six cases where storms were seen at all three stations. Propagation effects and measurement uncertainty presently prevent positive identification and tracking of a particular storm, but we see ways to improve this.

The answer to the title question is that the emissions show promise as a supplement to the present warning system. A question remains about the cost-effectiveness of doing the additional required research and deploying an operational sensor network.

E.E. Gossard and W.H. Hooke, **WAVES IN THE ATMOSPHERE: Atmospheric Infrasound and Gravity Waves - their Generation and Propagation**, Elsevier Scientific Publishing Company, New York (1975).

B.A. McIntosh, M.D. Watson and D.O. ReVelle, **"Infrasound from a radar-observed meteor,"** Can. J. Phys. 54, 655 (1976).

Abstract: The shock wave produced by the hypersonic entry of a sufficiently large meteoroid into the earth's atmosphere should be detectable at ground level. An array of microbarographs operated at Springhill Meteor Observatory recorded pressure waves on December 14, 1974, believed to be associated with a large meteor detected by the Springhill

radars. The time interval between the radar detection and the detection of pressure waves is consistent with an acoustic travel time from the location of the radar echo. Estimates of the meteor mass from the radar echo duration agree with mass estimates calculated from the blast-wave theory of ReVelle. Because no azimuth information was available for the meteor to compare with direction of arrival of the pressure waves, the association is not absolutely certain.

W.H. Beasley, T.M. Georges and M.W. Evans, **"Infrasound From Convective Storms. Part V. An Experimental Test of Electrical Source Mechanisms,"** J. Geophys. Res. 81, 3133 (1976).

Abstract: We performed an experiment to test the suggestion that the infrasound radiated by certain severe storms is caused by lightning. During the 1972 storm season we recorded at Boulder, Colorado, the rate and arrival direction of both VLF atmospherics and infrasound from severe thunderstorms in the midwestern United States. If infrasound were caused by lightning, we should have observed a good agreement in direction and time between the radio and acoustic emissions of lightning, within observational uncertainty. Fewer than half of the infra sound events showed such agreements with electromagnetic emissions. Those agreements can be attributed to noncausal coincidence. We argue that the correlation should be much higher if the infra sound emissions were caused by lightning. Some detailed case studies illustrate the differing phenomenologies of the emissions; for example, they show that the infrasound is probably emitted during an earlier stage of storm growth than that usually associated with lightning.

D.O. Revelle, **"On Meteor-Generated Infrasound,"** J. Geophys. Res. 81, 1217 (1976). [March 1]

Abstract: An analysis of the generation and propagation characteristics of infrasonic pressure waves excited during meteor entry into the earth's atmosphere is presented. Possible line source sound producing regions are determined for an assumed range of meteor entry parameters, gross fragmentation phenomena being neglected. A pressure wave model of a line source cylindrical blast wave produced by a high-velocity meteoroid in a continuum gas is then formulated by using similarity theory. It is found that the strong shock behavior of the blast wave is confined to a cylindrical region whose radius R_o is proportional to the product of the meteor's Mach number and its diameter. By using the numerical blast wave solutions of Plooster as initial conditions a description of the wave form far from the source is obtained. Both refraction and attenuation of the airwaves are then calculated separately in an approximate manner. For meteors with an associated $R_o \leq 10$ m for source altitude regions determined earlier, predicted attenuation is very severe. Dominant wave periods predicted for arrivals at the ground are 0.4-2.5 s for sources with $10 \leq R_o \leq 100$ m. Finally, infrasonic data from Goerke, from Shoemaker, and from Johnson and Wilson for four recent events are analyzed. Kinetic energy estimates which are obtained range from 10^{17} to 10^{22} ergs, each with an uncertainty of about 2 orders of magnitude.

A.D. Pierce and W.A. Kinney, **"Computational Techniques for the Study of Infrasound Propagation in the Atmosphere,"** Georgia Institute of Technology Technical Report No: AFGL-TR-76-0056, March 13, (1976). NTIS Number: ADA024951/6.

Abstract: A discussion is given of theoretical studies on infrasound propagation through the atmosphere which were carried out under the contract. Topics discussed include (1) the modification and adaptation of a computer program for the prediction of pressure signatures at large distances from nuclear explosions to include leaking guided modes, (2) the nature of guided infrasonic modes at higher infrasonic frequencies and the methods of extending waveform synthesis procedures to include higher frequencies, and (3) the propagation of infrasonic pressure pulses past the antipodes (over halfway around the globe). Summaries are included of all papers, theses, and reports written under the contract and conclusions and recommendations for future studies are given. [Descriptors: acoustic waves; atmospheres; wave propagation; computer programs; nuclear explosion damage; acoustic signatures; waveforms; synthesis; numerical analysis; high frequency. Identifiers: atmospheric acoustics; nuclear explosion effects; infrasonic waveform computer program; NTISDODXA; NTISDODAF.] NTIS Report No: ADA022978.

A.D. Pierce and W.A. Kinney, **"Atmospheric Acoustic Gravity Modes at Frequencies Near and Below Cutoff Imposed by Upper Boundary Conditions,"** Air Force Cambridge Research Laboratories Technical Report AFCRL-TR-75-0639, Hanscom AFB, March (1976). [March]

Abstract: Perturbation techniques are described for the computation of the imaginary part of the horizontal wavenumber (k_I) for modes of propagation. Numerical studies were carried out for a model atmosphere terminated by a constant sound-speed (478 m/sec) half space above an altitude of 125 km. The GR_0 and GR_1 modes have lower-frequency cutoffs. It was found that for frequencies less than 0.0125 rad/sec, the GR_1 mode has complex phase velocity; k_I varying from near zero up to a maximum of 3×10^{-4} km^{-1} with analogous results for the GR_0 mode. There is an extremely small frequency gap for each mode for which no poles in the complex k plane corresponding to that mode exist. These mark the transition from undamped propagation to damped propagation. In the complete Fourier synthesis, branch line contributions compensate for the absence of poles in these gaps. Computational procedures are described which facilitate the inclusion of the low-frequency portions of these modes in the waveform synthesis.

R.M. Jones and T.M. Georges, **"Infrasound from convective storms. III. Propagation to the Ionosphere,"** J. Acoust. Soc. Am. 59, 765 (1976). [April]

Abstract: We model mathematically the spectral features of infrasound observed in the ionosphere and believed to be radiated by severe thunderstorms. We explain the dominant 2-5 min wave period as an effect of atmospheric filtering; shorter periods are excessively attenuated by absorption in transit to the ionosphere, and longer periods are attenuated in portions of the atmosphere where the waves are evanescent because their frequencies are below the acoustic cutoff. An observed spectral "fine structure" within the 2-5 min band is explained in terms of resonant interactions between waves and the atmospheric temperature structure. Accurate quantitative modeling of all these details of the storm-to-ionosphere transmission coefficient requires numerical integration of the acoustic-gravity wave equation, including the effects of ground reflection, absorption, and partial reflections in the atmosphere.

A.D. Pierce and W.A. Kinney, "**Geometric Acoustics Technique in Far Field Infrasonic Waveform Synthesis,**" Air Force Geophysical Laboratories Technical Report AFGL-TR-76-0055, Hanscom AFB, (1976). NTIS Report No: ADA024721.

Abstract: A ray acoustic computational model for the prediction of long range infrasound propagation in the atmosphere is described. A cubic spline technique is used to approximate the sound speed versus height intervals. Techniques for finding ray paths, travel times, ray turning points, and rays connecting source and receiver are described. A parameter characterizing the spreading of adjacent rays (or ray tube area) is defined and methods for its computation are given. A method for determining the number of times a given ray touches a caustic is also described. Formulas are given for the computation of acoustic amplitudes and waveforms which involve a superposition of contributions from individual rays connecting source and receiver and which incorporate phase shifts at caustics. The possibility of a receiver being in the proximity of a caustic is considered in some detail and distinction is made between cases where the receiver is on the illuminated or shadow sides of a caustic. It is shown that a knowledge of parameters characterizing two rays at a point in the vicinity of a caustic provides sufficient information concerning the caustic to allow one to give a relatively accurate description of the acoustic field in its vicinity. The resulting theory involves Airy functions and uses concepts extrapolated form a theory published in 1951 by Haskell. The net result is a detailed computational scheme which should accurately cover the contingency of the receiver being near a caustic in the calculation of amplitudes and waveforms. A number of FORTRAN subroutines illustrating the method are given in an appendix. Limitations of the theory and suggestions for future developments are also given.

T.M. Georges and W.H. Beasley, "**Refraction of infrasound by upper-atmospheric winds,**" J. Acoust. Soc. Am. 61, 28 (1977). [January]

Abstract: We used realistic models of upper-atmospheric winds in a three-dimensional acoustic ray tracing program to calculate how much wind refraction alters acoustic transit speed and azimuth of arrival for long-distance paths. Transit speed varied by 20% or more, and bearing deviations of up to ten degrees were found, depending on the season and on the direction the waves travel. On the average, the predicted seasonal trends corresponded to observations, but the calculated standard deviations exceed the mean seasonal values, making simple corrections useless in individual cases. Furthermore, it is doubtful that variations of horizontally uniform winds alone can account for the large observed variability in refractive effects, specifically the large differences in bearing error at adjacent observatories. We show that realistic horizontal gradients of either temperature or wind could cause as much azimuthal refraction as our height-dependent wind models.

J.W. Reed, "**Atmospheric attenuation of explosion waves,**" J. Acoust. Soc. Am. 61, 39 (1977). [January]

Abstract: Observations of sound attenuation in the out of doors have shown an attenuation factor approximately dependent on the five-fourths power of frequency, rather than the square. Both power laws have been applied to calculations of yield-scalable pressure signatures from explosions to allow comparison of results with measurements of explosion-wave compression rise times. It appears that the five-fourths law better explains the long rise times observed, but there are still serious underpredictions. Nevertheless, this model has been applied to the problem of determining the requirements for pressure-gauge frequency response. At the low overpressures of concern in environmental monitoring, it

appears that a 1-kHz instrument response is more than adequate for recording explosion waves.

J.L. Bohannon, A.A. Few and A.J. Dessler, **"Detection of Infrasonic Pulses from Thunderstorms,"** Geophysical Research Letters 4(1), 49 (1977). [January]

Abstract: Acoustic data obtained from thunderstorm observations during 1975 near Socorro, New Mexico, and during 1976 at J.F. Kennedy Space Center, Florida, exhibited single, infrasonic pulses superimposed on the thunder signals arriving from the cloud in each of several thunder records. Only the Socorro data have been quantitatively analyzed thus far. These data show infrasonic pulses with periods of about 0.5 sec and amplitudes of about 0.1 N/m^2. We argue that these pulses were not generated by lightning channel heating. The pulse waveform is characterized by an initial compression followed by a rarefaction. Acoustic source reconstruction place the origins of these pulses in the cloud within essentially the same volume of space as the horizontal portions of the lightning channels. This volume is presumably in the lightning events. If the pulses are electrostatic in origin as predicted by Dessler [1973 then the data indicate a rapid (0.5 sec) intensification of the field prior to discharge.

D.H. Rind and W.L. Donn, **"Infrasound Observations of Variability During Stratospheric Warmings,"** Lamont-Doherty Geological Observatory Technical Report No: LDGO-2628 (ARO-14846.15-GS), July 6, (1977). NTIS Number: ADA095 603/7/HDM.

Abstract: None

G.S. Golitsyn, G.I. Grigor'yev and V.P. Dokuchayev, **"Generation of Acoustic-Gravity Waves by Meteor Motion in the Atmosphere,"** Izvestiya, Atm. and Ocean. 13(9), 633 (1977). [September]

Abstract: The low-frequency pulsed generation of internal infrasonic waves by meteoric bodies moving at supersonic speeds in the earth's atmosphere is considered. It is shown that meteors with large initial masses and velocities generate these waves efficiently due to the large amounts of energy released as they burn. The amplitudes of the pressure perturbation at the earth's surface and the electron density in the atmosphere are estimated for meteors in flight at altitudes of 50-120 km. The distribution of the radiated energy over the low-frequency wave spectrum is investigated. Expressions are derived for the total energy radiated in the internal and infrasonic waves.

D. Rind, **"Investigation of the Lower Thermosphere Results of Ten Years of Continuous Observations with Natural Infrasound,"** Lamont-Doherty Geological Observatory Technical Report No: LDGO-2716 (ARO-14846.16-GS), December 19, (1977). NTIS Number: ADA095602/9/HDM.

Abstract: None. Descriptors: Infrasonic radiation, ocean waves, reflection, thermosphere, wind, dirunal variations, seasonal variations.

W.L. Donn, "**Exploring the Atmosphere with Sonic Booms,**" American Scientist 66, 724 (1978).

Abstract: None

N.K. Balachandran, "**Infrasonic Signals from Thunder,**" J. Geophys. Res. 84, 1735 (1979). [April 20]

Abstract: Infrasonic signals from thunder have been observed at Palisades, New York, over a number of years. The signals are, in general, dominated by sharp refraction pulses with periods in the range of 0.4 - 1.0 s and peak-to-peak amplitude up to 10 dynes/cm^2 (1 N/m^2). The signals are found to be highly directional traveling almost vertically downward. Some aspects of these observations are in agreement with the theory of generation of sound by the sudden reduction of electrostatic field within a thunderstorm after a lightning discharge, originally proposed by *Wilson* (1920) and later refined by *Dessler* (1973). The spectra of the signals also indicate frequencies as low as 0.1 Hz. These low frequencies may be associated with other electrostatic stresses in the thundercloud. A low-amplitude compressional wave at the beginning of the signal is also observed. Sample computations of the thickness of the charged region and electric field strength are given.

D.R. Christie, K.J. Muirhead and A.L. Hales, "**Intrusive Density Flows in the Lower Troposphere: A Source of Atmospheric Solitons,**" J. Geophys. Res. 84, 4959 (1979). [August]

Abstract: This paper is concerned with the properties of complex propagating nonlinear tropospheric disturbances observed near Tennant Creek in the arid interior of the Northern Territory of Australia. Many of these unusual atmospheric disturbances resemble the well-known internal undular surges observed in the oceans and in inland stratified bodies of water. A description is presented of a wide variety of observations of solitary-wave-dominated evolving density intrusions, and it is shown that many of the features of these unique disturbances is governed by the boundary layer solitary atmosphere waves. Existing experimental evidence indicates that these disturbances originate primarily in the interaction of katabatic flows, propagating sea breeze vortices, and 'morning glory' phenomena with the stably stratified nocturnal radiation inversion.

E.J. Rickley and A.D. Pierce, **Detection and Assessment of Secondary Sonic Booms in New England; Final Rept.,**" Transportation Systems Center (Cambridge, MA) Technical Report No: TSC-FAA-80-10 (FAA-AEE-80-22), May (1980). NTIS Number: ADA088160/7/HDM.

Abstract: This report documents the results of a secondary sonic boom detection and assessment program conducted by the U.S. Department of Transportation, Transportation Systems Center in New England during the summer of 1979. Measurements of both acoustic and infrasonic signals were made. Measurement data and ray trace computations demonstrate that the secondary sonic booms frequently reported by New England residents are created by the Concorde passenger flight off the New England coast enroute to Kennedy Airport in New York City. Signal amplitudes show side fluctuations from flight to flight, from day to day, and with geographic locations. A brief set of measurements

made in Applebachsville PA, show a similar day to day variability and are correlated with Concorde flights into Dulles Airport in Virginia.

D. Rind, **"Microseisms at Palisades 3. Microseisms and Microbaroms,"** Lamont-Doherty Geological Observatory Technical Report No: ARO-14846.8-GS, November 12, (1980). NTIS Number: ADA091466/3/HDM.

Abstract: None. Descriptors: Microseisms, infrasonic radiation, ocean waves, sources, New York, oceanographic data, geophysics, reprints.

W.L. Donn and N.K. Balachandran, **"Gravity and Acoustic Waves Applied to the Dynamics and Kinematics of the Atmosphere; Final Rept. 15 May 74 - 1 Nov 80,"** Lamont-Doherty Geological Observatory Technical Report No: ARO-12286.3-GS and ARO-14846.11-GS, December (1980). NTIS Number: ADA093713/6/HDM.

Abstract: A generalized review of the work accomplished in the direct and spin-off areas supported over the past six years in the following areas is presented: (1) Use of infrasound as an Atmospheric Probe: Infrasonic signals from natural and artificial sources were used as a passive probe of the atmosphere. (2) Gravity Wave Program: In this study, an array of sensitive microbarographs (microbarovariographs) is used rather than microphones. Results so far show that surface gravity waves were related to the presence of wind shear aloft an often contribute continuous background perturbations. Gravity waves also shown to characterize the approach of warm fronts aloft, often well before the advent of precipitation and other storm features. Gravity waves were also shown to be of possible importance in generating thunderstorms through the triggering action at times of unstable or conditionally unstable conditions.

D.R. Christie, K.J. Muirhead and R.H. Clarke, **"Solitary waves in the lower atmosphere"** Nature 293, 46 (1981).

Abstract: Solitary waves are of intense interest in the physical and mathematical sciences. These nonlinear waves often seem to have a primary role in the asymptotic description of propagating disturbances in inland lakes and coastal waters, in the thermocline of the open sea and in the lower atmosphere. We present here new acoustic sounder observations of complex tropospheric solitary-wave disturbances at Tennant Creek in the arid interior of Australia, a description and interpretation of a new type of visible wave phenomena over northern Australia which appear as thin propagating cumulus cloud lines, and a discussion of observations at Burketown on the Gulf of Carpentaria of a new class of low-altitude propagating solitary-wave roll clouds which originate to the south. These observations, when correlated with observations at Tennant Creek, indicate that solitary-wave generating disturbances in the form of internal bores propagate over large distances.

A.J. Bedard and G.E. Greene, **"Case study using arrays of infrasonic microphones to detect and locate meteors and meteorites,"** J. Acoust. Soc. Am. 69(5), 1277 (1981). [May]

Abstract: On 22 April 1975, two infrasonic observatories in Colorado detected acoustic signals related to a fireball sighting. We use the infrasonic data in conjunction with surface and aircraft observations to investigate the signals. We deduce that the acoustic energy

originated from an explosive interaction of the object with the atmosphere at an altitude of about 25 km at a distance approximately 250 km from the observatories.

D.O. ReVelle and W.G. Delinger, **"Passive Acoustic Remote Sensing of Infrasound of Natural Origin,"** Proc. Int. Symposium of Acoustic Remote Sensing of the Atmosphere and Oceans, University of Calgary Press, Calgary, Alberta, Canada, V-6 to V-15 (1981).

Abstract: We have recently established two infrasonic observatories in the Flagstaff area for the purpose of monitoring naturally occurring infrasonic signals of meteorological origin. The two arrays of sensors each consist of four capacitance microbarographs with wind noise filters. Digital data recording has been carried out using two Cromemco dual disc drive microcomputers with each disc having a capacity of 92 kilobytes. This allows for minimum recording time of about 4 hours per disc. Wave sources being considered include: Thunder associated with the Arizona monsoon (see for instance Balachandran, 1979), infrasound from severe weather systems (Goerke and Woodward, 1966) and finally Mountain associated waves (Bedard, 1978). Among the numerous members of the atmospheric wave "zoo", we have also chosen to apply standard infrasonic data reduction procedures to a class of waves categorized as "Meteorite Impact" by Georges and Young (1972). As previously reported by ReVelle and Weatherill (1978 and 1980) waves generated by large meteor-fireballs entering the atmosphere can be used as a tool to determine the influx rate of large meteoroids (10^6 - 10^{10} grams). Using this latter well documented data set, a comparison will be made between previously determined source energy-wave parameter relationships and a high frequency extrapolation of the Lamb edge wave approach of Pierce and Kinney (1976).

D.R. Kraemer and F.L. Bartman, **"Infrasound from Accurately Measured Meteor Trails,"** Proc. Int. Symposium of Acoustic Remote Sensing of the Atmosphere and Oceans, University of Calgary Press, Calgary, Alberta, Canada, V-31 to V-49 (1981).

Abstract: Infrasonic signals generated by meteor entry into the earth's atmosphere have been measured by an array of microphones established near Sioux Falls, S.D. The trajectories of the meteors have been precisely determined from photographs taken by the Smithsonian Institution's Prairie Network meteor camera system.

Three meteor entries are examined in detail. One of these produced sound that was measured at the microphone array; the other two did not. The nature of the measured infrasound is compared with the predicted values of the idealized cylindrical line source model for meteor sound. Necessary modifications to the existing theory which predicts the infrasonic wave arriving at the ground, are presented, and good agreement is observed between measurement and theory. The fact that sound was not received at the microphone array for the remaining two meteors is shown to be consistent with the cylindrical line source theory and refraction effects due to the atmospheric temperature and wind structure.

L. Liszka, **"Studies of the Stratospheric and Mesospheric Wind System and Temperature Distribution from Observations of Infrasonic Waves Generated During Regular Concorde Flights,"** Kiruna Geofysiska Institute (Sweden) Report KGI-176; ISSN-0347-6405, September (1981). NTIS Number: N82-19789/8/HDM.

Abstract: The applications of infrasonic recording to atmospheric studies are discussed and results from Concorde flight observations at four recording stations are presented. The

Concorde aircraft is considered as an infrasonic source located at a known distance, strong enough to be recorded at distances of up to 5,000 km. It is assumed that the direction of propagation of the infrasound produced by the aircraft is determined by the Mach cone, i.e., basic principles of geometrical acoustics are applied. At each station, azimuth and horizontal phase velocity of the arriving signal were recorded as a function of time. As the propagation of infrasound in the atmosphere is strongly influenced by wind and temperature profiles, Concorde recordings in the infrasound range provide information about the atmosphere-horizontal wind and temperature variations. Variations in propagation time, angle of arrival and phase velocity of recorded infrasonic signals are interpreted in terms of temporal and spatial variations of the wind system.

G.G. Sorrells, **"The Investigation of the Combined Use of Microbarometric and Seismic Data to Detect and Identify Infrasonic Signals; Semi-Annular Rept. No. 1,"** Teledyne Geotech Technical Report No: TR-81-11 (AFOSR-TR-81-0890), September (1981).

Abstract: There is a need to acquire an infrasonics monitoring capability to supplement existing atmospheric nuclear test surveillance systems. A research program to investigate the combined use of a three-component seismograph and a microbarograph to supply the desired monitoring capability is currently underway. A temporary observatory consisting of a five-element microbarograph array and a three-component, long-period seismograph system has been established near McKinney, Texas, to acquire the experimental data necessary to perform the investigation. Preliminary analysis of the data indicates that the infrasonic signal-to-noise ratio will be greater at the output of a vertical seismograph than at the output of a microbarograph in a frequency range extending roughly from 0.005 Hz to 0.05 Hz during intervals of atmospheric turbulence.

C.R. Wilson, **"Antarctic Atmospheric Infrasound; Final progress Rept.,"** University of Alaska Final Technical Report No: AFOSR-TR-82-0107, November (1981). NTIS Report Number: ADA111957/7/HDM.

Abstract: A summary is given of the project chronology and the reports describing our research in Antarctic Atmospheric infrasound. Analysis of selected infrasonic signals is discussed and a list is given of all infrasonic waves received on the digital system with correlation coefficient greater than 0.6.

B.A. McIntosh, **"Natural and Unnatural Infrasound,"** Herzberg Institute of Astrophysics, Planetary Sciences Technical Report SR-82-1, April (1982),

Abstract: None.

E. Kessler, **"Thuderstorms: A Social, Scientific, and Technological Documentary. Volume 3. Instruments and Techniques for Thuderstorm Observation and Analysis,"** NOAA Report No: NOAA-82102704, April (1982), NTIS Number: PB83-146076.

Abstract: Contents: Station networks for storm observation; Tornado interception with mobile teams; Observations from instrumented aircraft; Photgrammetry of thunderstorms; Storm acoustics; Infrasound from thunderstorms; Sferics and other electrical techniques for storm investigations; Observations and measurement of hailfall.

A.J. Dragt, **"Review and Evaluation of Physical Sciences Program, AFOSR (Air Force Office of Scientific Research); Final Rept. 1 May - 30 Sep,"** University of Maryland Technical Report No: AFOSR-TR-89-1638, May (1982). NTIS Number ADA21504/7/HDM.

Abstract: In the past year, the University of Maryland has monitored and arranged for the convening of 10 Research Evaluation Groups or Panels to review and evaluate various aspects of the Physical Sciences Program, AFOSR, ranging over such diverse disciplines as high power microwave technology, electromagnetic radiation, laser physics, seismic detection, photo acoustics, infrasonics, thin films, flight dynamics, environmental toxicology, and biomedical sciences. These reviews and evaluations involved approximately 539 person-days of effort by independent scientists selected from universities and industry for their expert knowledge and experience in the requisite fields.

J.R. Murphy, H.K. Shah and T.K. Tzeng, **"Analysis of Low Frequency Ground Motions Induced by Near-Surface and Atmospheric Explosions,"** S-Cubed Technical Report No: SSS-R-82-5679, August 1, (1982). NTIS Number: ADA133218/8/HDM.

Abstract: This report describes the results of a preliminary analysis of the effects of variations in height of burst (HOB) on the low frequency ground motions induced by near-surface and atmospheric explosions. A mathematical model which can be used to simulate this component of the explosively generated ground motions is described and applied to the parametric investigation of the effects of HOB on a prototype 1 kt nuclear explosion detonated over a site model approximating the subsurface geology at Yucca Flat on the Nevada Test Site. These simulations indicate that although the details of the airblast loading vary considerably with HOB, the corresponding induced low frequency.

F.J. Mauk and G.G. Sorrells, **"Seismic Methods of Infrasonic Signal Detection; Annual Report,"** Teledyne Geotech Report No: TR-82-5 (AFOSR)-TR-83-0131, September 30, (1982). NTIS Number: ADA126454/8/HDM.

Abstract: Infrasonics monitoring using a three-component borehole seismograph and surface microbarograph array show that within a frequency band extending between about 0.005 Hz to about 0.05-0.1 Hz, depending on local wind conditions, the infrasonic depth will be no worse than, and can be considerably better than, that observed on a microbarogram. Results lend credence to the hypothesis that, within this frequency band, infrasonic signals generated by sources in the low to moderate kiloton yield range can be seismically observed and can be positively identified without the aid of microbarograph data.

J.V. Olson, C.R. Wilson, J. Collier and B.N. McKibben, **"Final Progress Report for Contract F49620-81-C-0091; Rept. for 1 Oct 81 - 30 Sep 82,"** Alaska University Technical Report No: AFOSR-TR-83-0130.

Abstract: The morphology of microbarom infrasonic waves as observed in Antarctica is given for 1981 observations from Windless Bight. Application of pure-state filtering to infrasonic array data is described. Off-line frequency domain analysis software is presented for infrasonic wave analysis.

F. Badavi, R. Meredith and J. Becher, "**Propagation of Sound Through the Earth's Atmosphere,**" Old Dominion University Technical Report No: TR-PTR-82-17, December (1982). NTIS Number: N83-15040/9/HDM.

Abstract: The infrasonic signatures generated by the main blade slap rate of a helicopter were used in an effort to detect infrasound generated by clear air turbulence. The artificially produced infrasound and the response of the data acquisition system used are analyzed. Flight procedures used by the pilot are described and the helicopter flight information is tabulated. Graphs show the relative frequency amplitudes obtained at various microphone locations.

"**AMERICAN NATIONAL STANDARD: Estimating Airblast Characteristics for Single Point Explosions in Air, With a Guide to Evaluation of Atmospheric Propagation and Effects,**" Standards Secretariat, Acoustical Society of America, ANSI S2.20-1983, (1983).

Abstract: This standard provides consensus quantitative definitions of explosion characteristics for a single point explosion in air, along with methodologies for scaling these characteristics for a wide range of yield and ambient air conditions. Factors for use with common solid explosives are also included. Methods are provided for predictions of long range propagation under atmospheric refractive influences. Target damage estimation procedures are provided for use in explosion operation planning and evaluation.

C. Khalaf and J.W. Stoughton, "**Software Development for Infrasound Measurement System; Final Report,**" Old Dominion University Technical Report No: NASA-CR-173061, 15 May (1983). NTIS Number: N83-34609/8/HDM

Abstract: A software package developed for detection and analysis of infrasounds produced by air turbulence is described.

J.W. Reed and H.W. Church, "**Airblast Predictions with Meteorological and Microbarograph Measurements,**" Sandia Laboratory Report No. SAND-84-0297C, in the Proceedings of a DNA direct course symposium, Adelphi, MD, USA, April 9, 1984., April (1984). NTIS Number: DE84009932/HDM.

Abstract: Recent explosion tests have demonstrated elements of anomalous behavior, in both airblast propagation and cloud growth, that could not be easily explained by routinely available meteorological observations made at shot time. To better detail the near-field atmospheric structure during DIRECT COURSE tests at White Sands Missile Range (WSMR), additional measurement systems were employed in hope of aiding interpretation of any further anomalies that might occur. Besides regular WSMR rawinsonde balloon (raob) measurements launched from SOTIM-3 site, WSMR also provided a mobile 23 m meteorological tower equipped for continuous recording of wind and temperature at three levels. Sandia operated its Tethersonde to give a succession of ascending and descending recordings of wind, temperature, moisture, and pressure heights to above 800 m above ground. Finally, an experimental Doppler-laser remote sensing system was operated by NOAA, with results given in another presentation at this symposium. As with other large explosion tests, a weather-watch and blast prediction service was provided during the countdown, so to provide warning to the Test Director of any possible damaging or

hazardous airblast propagation to great distances. Six microbarograph (MB) stations were operated in various communities to document the actual airblast wave passage, for use in verifying predictions as well as in validation or rejection of any damage claims that resulted.

B.A. McIntosh and D.O. Revelle, "**Traveling Atmospheric Pressure Waves Measured During a Solar Eclipse,**" J. Geophys. Res. 89, 4953 (1984). [June]

Abstract: An array of microbarographs near Saskatoon, Saskatchewan, detected traveling pressure waves at a time and with a direction of motion that indicates an association with the solar eclipse of February 26, 1979. The velocity was 10 m/s moving toward azimuth 65°; the wave period and amplitude were approximately 120 s and 12.0 Pa, respectively; the duration of the wavetrain was approximately 3 hours. The possibility that it was a free gravity wave is examined and rejected. A possible source mechanism similar to the low level nocturnal jet is suggested.

J.G. Swanson and J.C. Woerpel, "**Seismic Observation of Infrasonic Signals; Final Rept. 15 Jul 83 - 14 Jul 84,**" Teledyne Geotech Technical Report No: TR-84-7; AFOSR-TR-84-1206, November 1, (1984). NTIS Number: ADA149574/6/HDM.

Abstract: A sliding pure-state filter attenuated wind-induced noise recorded by individual elements of a four-element microbarograph array an average of 22 dB. Summation of the processed microbarograms yielded an additional 5 dB attenuation, whereas summation of the unprocessed microbarograms attenuated the noise 6 dB relative to the individual microbarograms. A sliding pure-state filter yielding separate estimates of linearly and elliptically polarized arrivals, applied to the outputs of three-component, long-period inertial seismograms at a site near McKinney, Texas, and at Seismic Research Observatories ANMO, BOCO, and GRFO detected infrasonic signals from five eruptive sequences of El Chicon volcano. Application of pure-state filter improved the signal-to-noise ratio of the seismically detected infrasonic signals an average of 14 dB. A combination of adaptive beam forming and pure-state filtering applied to the outputs of seven elements of the NORSAR three-component, long-period array marginally detected an infrasonic signal from the largest El Chichon eruption.

C.S. Khalaf and J.W. Stoughton, "**Design of Infrasound-Detection System Via Adaptive LMSTDE Algorithm; Final Rept,**" Old Dominion University (VA) Technical Report No: NASA-CR-176531, November (1984). NTIS Number: N86-19301/8/HDM.

Abstract: A proposed solution to an aviation safety problem is based on passive detection of turbulent weather phenomena through their infrasonic emission. This thesis describes a system design that is adequate for detection and bearing evaluation of infrasounds. An array of four sensors, with the appropriate hardware, is used for the detection part. Bearing evaluation is based on estimates of time delays between sensor outputs. The generalized cross correlation (GCC), as the conventional time-delay estimation (TDE) method, is first reviewed. An adaptive TDE approach, using the least mean square (LMS) algorithm, is then discussed. A comparison between the two techniques is made and the advantages of the adaptive approach are listed. The behavior of the GCC, as a Roth processor, is examined for the anticipated signals. It is shown that the Roth processor has the desired effect of sharpening the peak of the correlation function. It is also shown that the LMSTDE

technique is an equivalent implementation of the Roth processor in the time domain. A LMSTDE lead-lag model, with a variable stability coefficient and a convergence criterion, is designed.

B.D. Palmer, **"Atmospheric Fractionation of Nuclear Debris; Thesis,"** Arkansas University (Fayetteville) Technical Report No: DOE/EV/02529-T8, (1984). NTIS Number: DE87008116/HDM.

Abstract: The first phase of the thesis work is concerned with the study of the seasonal variation of the strontium-90 fallout concentration in rainfall and the effect the recent US and USSR test series had upon this variation. The second phase of the thesis is concerned with an interpretation of the fractionation of the fission products in the atmosphere on the basis of more recent experimental data obtained in this laboratory. Other researchers' work is also discussed.

A.J. Bedard, Jr., **"Optimizing the Use of Surface Sensors for Wind Shear Detection,"** J. Aircraft 21, 971 (1984). [December]

Abstract: Optimizing the use of surface sensors for wind shear detection involves addressing a broad range of physical processes and time and spatial scales. In addition to the operational considerations of providing timely warnings with systems that are practical to install and maintain. Concentrating on thunderstorm gust fronts and down-bursts, important properties for detection and warning are reviewed from the perspectives of both analytical calculations and experimental measurements. Calculations of such properties as the forms of the low-level divergence fields and dynamic pressure changes indicate important measurement scales for the use of combined sensing systems of anemometers and pressure sensors.

J.H. Hunter, **"Kingfish Striations and the Kelvin-Helmholtz Instability. Part 1,"** Los Alamos National Laboratory Technical Report No: LA-10566-MS, October (1985). NTIS Number: DE86004378/HDM.

Abstract: The role of the Kelvin-Helmholtz instability in initiating the formation of the density striations observed in the Kingfish fireball is examined. Two idealized models are proposed for the velocity shear layer on the sides of the fireball, each of which includes essential characteristics of the Kingfish event insofar as the development of Kelvin-Helmholtz instabilities is concerned. A complete linear analysis is presented for each model.

A.J. Zuckerwar, **"Infrasonic Emissions from Local Meteorological Events: A Summary of Data Taken Throughout 1984,"** NASA TM-87686, February (1986).

Abstract: Records of infrasonic signals, propagating through the Earth's atmosphere in the frequency band 2-16 Hz, were gathered on a three-microphone array at Langley Research Center throughout the year 1984. Digital processing of these records fulfilled three functions: time delay estimation, based on an adaptive filter: source location, determined from the time delay estimates; and source identification, based on spectral analysis. Meteorological support was provided by significant meteorological advisories, lightning locator plots, and daily reports from the Air Weather Service. The infrasonic data are organized into four characteristic signatures, one of which is believed to contain

emissions from local meteorological sources (low level wind shear, microbursts, etc.). This class of signature prevailed only on those days when a major global meteorological event appeared in or near the eastern United States. Eleven case histories are examined. Practical application of the infrasonic array in a low level wind shear alert system is discussed.

G.E. Greene and A.J. Bedard, **"Infrasound from Distant Rocket Launches,"** National Oceanic and Atmospheric Administration Technical Report No: NOAA-TM-ERL-WPL-131, February (1986). NTIS Number: PB86-182771/HDM.

Abstract: From 1959 through 1969 low-frequency (0.02 - 1.0 Hz) acoustic signals related to missile launches from Cape Canaveral were recorded by an infrasonic station in Washington, D.C.. Although the characteristics of these signals are considerably more variable than those from other known sources, the acoustic signatures can resemble those from sources both natural and man-made. A general summary includes 61 missile-related signals with specific examples of their features.

A.J. Zuckerwar, J.W. Stroughton and C.W. Khalaf, **"Infrasonic Emissions from Local Meteorological Events: A Summary of Data Taken Throughout 1984,"** NASA Technical Report No: NASA-TM-87686, February (1986). NTIS Number: N86-21281/8/HDM.

Abstract: Records of infrasonic signals, propagating through the Earth's atmosphere in the frequency band 2 to 16 Hz, were generated on a three microphone array at Langley Research Center throughout the year 1984. Digital processing of these records fulfilled three functions: time delay estimation, based on an adaptive filter; source location, determined from the time delay estimates; and source identification, based on spectral analysis.

Meteorological support was provided by significant meteorological advisories, lightning locator plots, and daily reports from the Air Weather Service. The infrasonic data are organized into four characteristic signatures, one of which is believed to contain emissions from local meteorological sources. This class of signature prevailed only on those days when major global meteorological events appeared in or near to eastern United States. Eleven case histories are examined. Practical application of the infrasonic array in a low level wind shear alert system is discussed.

C. Delclos, **"Treatment of Multicomponent Microbarographic Signals Excited by High Power Explosions,"** Institut National Polytechnique de Grenoble Technical Report (In French) No: FRCEA-TH-140, April (1986). NTIS Number: DE88756017/HDM.

Abstract: A method for analysis of microbarographic signals recorded on a sensor network is developed, the aim is the localization of the source with maximum accuracy. It is shown that the method using the interspectral matrix finds a direct application in the discrimination of wave from high power explosions in a noisy environment. Its powerfulness is demonstrated on actual signals (explosion of the volcano Mt St Helens) allowing interesting results on propagation mechanisms (Brunt period. Lamb modes and acoustic modes).

A.J. Bedard, J. Intrieri and G.E. Greene, **"Infrasound Originating from Regions of Severe Weather,"** in Proceedings of the 12th Congress on Acoustics, Toronto, Canada, July (1986).

Abstract: Investigating atmospheric acoustics in the frequency range from about 0.5 Hz to 20 Hz, we found one class of infrasound originating from regions of severe weather. The experimental techniques, passband, and analysis methods differ from past investigations documented by *Bowman and Bedard* (1971), and *Georges* (1973), who concentrated on frequencies less than 0.1 Hz. Other investigators studied storm emissions at higher frequencies (1 to several hundred Hz), emphasizing acoustic measurements from lightning at relatively short ranges (e.g., *Few* (1979). In the 0.5 to 20 Hz passband, *Balachandran* (1973) and *Bohannonet al.*, (1977) have reported observations of infrasound from severe weather. Because our infrasonic observatory is located in a region extensively instrumented meteorological events. In this paper we show that the observed infrasound is highly correlated with severe weather and that cloud-to-ground lightening is not the source of the acoustic signals.

R.M. Jones, J.P. Riley and T.M. Georges, **"HARPA: A Versatile Three-Dimensional Hamiltonian Ray-Tracing Program for Acoustic Waves in the Atmosphere above Irregular Terrain; Special Rept.,"** National Oceanic and Atmospheric Administration Report No: NOAA/SW/MT-87/001A, August (1986). NTIS Number: PB87-132031/HDM.

Abstract: The modular FORTRAN 77 computer program traces the three-dimensional paths of acoustic rays through continuous model atmospheres by numerically integrating Hamilton's equations -- a differential expression of Fermat's principle. The user specifies an atmospheric model by writing closed-form formulas for its three-dimensional wind and temperature (or sound speed) distribution, and by defining the height of the reflecting terrain vs. geographic latitude and longitude. Some general-purpose models are provided, or users can readily design their own. In addition to computing the geometry of each raypath, HARPA can calculate pulse travel time, phase time, Doppler shift (if the medium varies in time), absorption, and geometrical path length. The program prints a step-by-step account of a ray's progress. The 410-page documentation describes the ray-tracing equations and the structure of the program, and provides complete instructions, illustrated by a sample case.

NTIS, **"Infrasonics: Theory and Applications. 1975-August 1986 (Citations from the INSPEC: Information Services for the Physics and Engineering Communities Database,"** NTIS Report No: PB86-874922/HDM, September (1986). NTIS Number: PB86-874922/HDM.

Abstract: This bibliography contains citations concerning theoretical, experimental, and practical studies on infrasound. Low frequency sound wave generation from wind, water, volcanoes, earthquakes, and meteorites is discussed. Industrial sources are also considered. Measurement of infrasonic ambient air noise, applications as a cleaning tool, a probing tool, and as in indicator for earthquakes and severe weather conditions are presented. Infrasound associated with lightning is also included. (Contains 183 citations fully indexed and including a title list.).

J.W. Reed, **"Air Pressure Waves From Mount St. Helens Eruptions,"** J. Geophys. Res. 92, 11,979 (1987). [October 20]

Abstract: Weather station barograph records as well as infrasonic recordings of the pressure wave from the Mount St. Helens eruption of May 18, 1980, have been used to estimate an equivalent explosion airblast yield for this event. Pressure amplitude versus distance patterns in various directions compared with patterns from other large explosions, such as atmospheric nuclear tests, the Krakatoa eruption, and the Tunguska comet impact, indicated that the wave came from an explosion equivalent of a few megatons of TNT. The extent of tree blowdown is considerably greater than could be expected from such an explosion, and the observed forest damage is attributed to outflow of volcanic material. The pressure-time signature. The pressure time signature obtained at Toledo, Washington, showed a long, 13 min-duration negative phase as well as a second, hour-long compression phase, both probably caused by ejecta dynamics rather than standard explosion wave phenomenology. The peculiar audibility pattern, with the blast being heard only at ranges beyond about 100 km, is explicable by finite amplitude propagation effects. Near the source, compression was slow, taking more than a second but probably less than 5 s, so that it went unnoticed by human ears and susceptible buildings were not damaged. There was no damage at Toledo (54 km), where the recorded amplitude would have broken windows with a fast compression. An explanation is that wave emissions at high elevation angles traveled to the upper stratosphere, where low ambient air pressures caused this energetic pressure oscillation to form a shock wave with rapid, nearly instantaneous compression. Atmospheric refraction then returned part of this wave to the ground level at long ranges, where the fast compressions were clearly audible.

J.W. Reed, **"Climatological Assessment of Explosion Airblast Propagation,"** Sandia National Laboratory Technical Report SAND-86-2180C, (1986).

Abstract: None.

J.P. Mutschlecner and R.W. Whitaker, **"Propagation of Near-Infrasound over Long Ranges,"** Los Alamos National Laboratory Report No: LA-UR-87-258; CONF-8610228-1, October 27, (1986). NTIS Number: DE87005095/HDM.

Abstract: This paper describes the results of basic research on the physics of infrasound propagation, both for predictive purposes and signal interpretation. The following aspects were considered: (1) attenuation, (2) seasonal effects, (3) wave effects, (4) average velocity, (5) azimuth deviations, (6) coherence, and (7) surface effects. The primary region of interest was approximately 0.1 Hz to 10 Hz with corresponding wavelengths of 3000 to 30 meters.

C.R. Wilson and B.N. McKibben, **"Antarctic Atmospheric Infrasound; Final technical Rept. 1 Jul 81 - 30 Sep 84,"** Alaska University, Fairbanks Geophysical Institute Technical Report No: AFOSR-TR-87-0162, November (1986). NTIS Number: ADA176804/3/HDM.

Abstract: In order to monitor atmospheric infrasonic waves in the passband from 0.1 to 0.01 Hz a digital infrasonic detection system was installed in Antarctica on the Ross Ice shelf near McMurdo Station on McMurdo Sound. An array of seven infrasonic microphones subtending an area of about 35 sq km was operated in Windless Bight. The analog microphone data was telemetered to McMurdo station where the infrasonic data were digitized and subjected to on-line real-time analysis to detect traveling infrasonic waves with periods from 10 to 100 seconds. During the period of operation of the Antarctic

infrasonic observatory, hundreds of infrasonic signals were detected in association with many natural sources such as the aurora australis, marine storm sea-air interactions, volcanic eruptions, mountain generated lee-wave effects, large meteors and auroral electrojet supersonic motions.

A. Doury, **"Comparative Evaluation between Radioactive Fallout of Chernobylsk-4 Reactor and Atmospheric Nuclear Explosion,"** CEA Centre d'Etudes Nucleaires de Fontenay-aux-Roses Technical Report (in French) No: CEA-DAS-328, November (1986). NTIS Number: DE88752404.

Abstract: In this paper the author compares the atmospheric diffusion coefficients and the radioactive fallout for Chernobylsk-4 reactor and atmospheric nuclear explosions.

C.L. Longmire, R.M. Hamilton and J.M. Hahn, **"Nominal Set of High-Altitude EMP Environments,"** Mission Research Corporation Technical Report No: ORNL/SUB-86-18417/1; MRC-R-991R-1, February (1987). NTIS Number: DE87006022/HDM.

Abstract: This report presents high-altitude EMP (HEMP) environments calculated by the CHAP code for a nominal large yield burst at 400 km over the central U.S. Nominal, unclassified weapon output parameters were used, along with unclassified EMP theory and calculational techniques. While the resulting environments do not represent upper bounds, they should be useful in developing understanding of the effect of HEMP on electrical and electronic systems. The calculated environments illustrate the wide variability of the HEMP from a single burst, depending on ground range and azimuth from ground zero. Analytic fits to the HEMP fields are provided to facilitate coupling calculations. The CHAP results are justified by a detailed examination of Compton currents, air conductivities, and the resulting fields. It is shown that both HEMP theory and the calculations conserve energy scrupulously.

V.E. Quinn, **"Analysis of Operation TEAPOT Nuclear Test ZUCCHINI Radiological and Meteorological Data,"** National Weather Service (Las Vegas, NV) Technical Report: NVO-307, March (1987). NTIS Number: DE87007529/HDM.

Abstract: This report describes the Weather Service Nuclear Support Office (WSNSO) analyses of the radiological and meteorological data collected for the ZUCCHINI nuclear test of Operation TEAPOT. Inconsistencies in the radiological data and their resolution are discussed. The methods of normalizing the radiological data to a standard time and estimating fallout-arrival times are presented. The meteorological situations on event day and the following day are described. A comparison of the WSNSO fallout analysis with an analysis performed in the 1950's is presented. The radiological data used to derive the WSNSO 1986 fallout pattern are tabulated in an appendix.

A.R. Jacobson and R.C. Carlos, **"Observations of Prolonged Ionospheric Anomalies Following Passage of an Infrasound Pulse Through the Lower Thermosphere,"** Los Alamos National Laboratory Technical Report No: LA-10986-MS, June, (1987). NTIS Number DE87012706/HDM.

Abstract: We have studied the Doppler spectra of E-layer vertical-incidence HF soundings around the time of passage of a brief (duration approx. 10s) acoustic shock. Following the

exit of the shock from the reflection volume, there occurred a several-minute episode of spectral derangement. We have analyzed this derangement in some detail and have related it to other studies of possibly the same phenomenon.

F.A. Crowley and J.I. Blaney, **"Surface Disturbances Produced by Low-Level, Subsonic B-1 Aircraft,"** Weston Observatory Technical Report No: SCIENTIFIC-1; AFGL-TR-87-0325, November 15, (1987). NTIS Number: ADA192257/4/HDM.

Abstract: Properties of infrasonic and seismic disturbances excited by low level, subsonic B-1 flights over the Arkansas River Valley near La Junta, Colorado are measured and studied for different wind conditions. The study emphasizes the role seismics and infrasonics might play to detect and track aircraft overflying a distributed network of pressure sensors and seismometers. The work concludes that carefully sited and calibrated seismic nodal elements, operating at low data rates, have a high potential to provide timely azimuth information for tracking.

J.W. Reed, **"Climatological Assessment of Explosion Airblast Propagation,"** Sandia National Laboratory Technical Report No: SAND-86-2180C (Conference Proceeding), (1987). NTIS Number: DE87010510/HDM.

Abstract: Sound waves or explosion airblast waves are refracted by the atmosphere depending upon temperature-dependent sound speeds and winds at various altitudes. In comparison with propagation expected from a spherical explosion overpressure-distance function, long-range overpressures (below about 2 kPa) may be attenuated by a strong decrease (gradient) in sound velocity with height; they may be enhanced by an inversion or increasing sound velocity with height; or there may be blast focusing by as much as 3 to 5X from complex sound velocity structures. In general, for a wave passing through a layer where sound velocity decreases with height, wave normals (rays) are curved upward away from ground, so that overpressures are subject to excess attenuation compared to undistorted radial propagations from an assumed model explosion. In a layer were sound velocity increases with height, shock rays are curved downward toward the ground. When they strike ground, they are almost perfectly reflected, at least for the low frequencies and long wave lengths of most explosion tests, and follow repetitious paths. At moderate to long ranges, the result is a restriction to near cylindrical wave expansion, rather than spherical, with an associated amplification of wave overpressure, by comparison with an undistorted spherically expanding wave. In the more complex dogleg case, with a decreasing sound velocity strata above the surface capped by a layer of increasing sound velocities (to a value higher than at the surface), the result may be a folding of the wave front to form a caustic (in 3-D) or a focus that may reach the ground. Very strong overpressure amplifications may develop in such foci; 5X overpressure amplifications (25X in energy flux) have been recorded.

D.B. Harris, **"Proceedings of the Array Signal Processing Symposium: Treaty Verification Program,"** Lawrence Livermore National Laboratory Technical Report No: CONF-8707152-VUGRAPHS, February (1988). NTIS Number: DE8808346/HDM.

Abstract: A common theme underlying the research these groups conduct is the use of propagating waves to detect, locate, image or otherwise identify features of the environment significant to their applications. The applications considered in this symposium are verification of nuclear test ban treaties, non-destructive evaluation (NDE) of manufactured components, and sonar and electromagnetic target acquisition and tracking.

These proceedings cover just the first two topics. In these applications arrays of sensors are used to detect propagating waves and to measure the characteristics that permit interpretation. The reason for using sensor arrays, which are inherently more expensive than single sensor systems, is twofold. By combining the signals from multiple sensors, it is usually possible to suppress unwanted noise, which permits detection and analysis of weaker signals. Secondly, in complicated situations in which many waves are present, arrays make it possible to separate the waves and to measure their individual characteristics (direction, velocity, etc.) Other systems (such as three-component sensors in the seismic application) can perform these functions to some extent, but none are so effective and versatile as arrays. The objectives of test ban treaty verification are to detect, locate and identify underground nuclear explosions, and to discriminate them from earthquakes and conventional chemical explosions. Two physical modes of treaty verification are considered: monitoring with arrays of seismic stations (solid earth propagation), and monitoring with arrays of acoustic (infrasound) stations (atmospheric propagation). The majority of the presentations represented in these proceedings address various aspects of the seismic verification problem.

J.C. Hardin and D. Stuart Pope, **"Prediction of the Spectrum of Atmospheric Microburst Noise in the Range 2-20 Hz,"** NASA Langley Report (1988).

Abstract: An engineering estimate of the spectrum of atmospheric microburst noise radiation in the range 2-20 Hz is developed. This prediction is obtained via a marriage of standard aeroacoustic theory with a numerical computation of the relevant fluid dynamics. The analysis is useful in the interpretation of atmospheric noise measurements and is illustrative of a class of problems which cannot be approached through such "computational aeroacoustics" techniques.

Swedish Institute of Space Physics, **"Sweedish Institute of Space Physics. Annual Report 1987,"** Kiruna Geofysika Inst. (Sweden) Technical Report No: NEI-SE-33, (1988). NTIS Number: DE89614751/HDM.

Abstract: The main task of the institute is to conduct research and perform observatory measurements in the field of space physics. It shall also provide postgraduate education in space physics. IRF consists of four divisions. The largest division as well as the main office is situated in Kiruna. The other divisions are the Laboratory of Mechanical Waves in Soerfors, the Umeaa Division and the Uppsala Division. Lycksele Ionospheric Observatory belongs to the Kiruna Division. The different divisions have independent research programmes and separate research grants. The field of study taking up most resources at IRF Kiruna today is the in situ hot plasma investigations. We develop and build various types of plasma spectrometers for the energy range from 1 eV to several hundred keV. To date instruments constructed in Kiruna have been flown on eight satellites and more than 40 sounding rockets. We have also developed ground support equipment for a plasma experiment on board the Giotto spacecraft. The laboratory of Mechanical Waves concentrates on applied and basic research concerning infrasound and low frequency vibration; development of methods for detection and signal processing of mechanical waves, and investigation of the middle atmosphere through measurements of the propagation of infra-acoustic waves. The Umeaa and Uppsala divisions have their main interests in the areas of space plasma physics, e.g., wave particle interactions and high latitude ionospheric phenomena.

A.J. Bedard, G.E. Greene, J. Intrieri, and R. Rodriguez, **"On the Feasibility and Value of Detecting and Characterizing Avalanches Remotely by Monitoring Radiated Sub-Audible Atmospheric Sound at Long Distances,"** Engineering Foundation Conference, Santa Barbara, CA, 10-15 July (1988).

Abstract: Because avalanches frequently occur in remote areas, it is often difficult to establish the timing or extent of snow movements. Such information is valuable for verifying avalanche prediction models, as well as establishing regional statistics. We summarize techniques developed for measuring low-frequency, small-amplitude sound waves in the atmosphere. Infrasonic observations made along the front range near Boulder Colorado, suggest that it may be possible to detect low-frequency sound waves related to avalanches at distances of hundreds of kilometers. Several acoustic radiation mechanisms are possible. Source region acoustic measurements should be made of controlled avalanches in an effort to understand the acoustic radiation sources, and optimize measurement techniques.

A.J. Bedard, **"Infrasound from Natural Sources,"** Proc. Inter-Noise 88, Avingnon, France, August 30, (1988).

Abstract: None.

M. West, F. Walkden and R.A. Sack, **"The Acoustic Shadow Produced by Wind Speed and Temperature Gradients Close to the Ground,"** Applied Acoustics 27, 239 (1989).

Abstract: The residue solutions of Pierce and of Berry & Daigle for predicting sound pressure in a shadow region are described.

A new ray based procedure for obtaining the average sound speed gradient required in both solutions is shown to improve the accuracy of predicted peak pressures.

C. Delclos, E. Blanc, P. Broche, F. Glangeaud and J.L. Lacoume, **"Processing and Interpretation of Microbarograph Signals Generated by the Explosion of Mount St. Helens,"** J. Geophys. Res. 95, 5485 (1990).

Abstract: Following the eruption of Mt. St. Helens volcano on May 18, 1980, atmospheric waves were recorded by a network of microbarographs located over 7000 km from the source. Analysis of these data requires the use of complex processing techniques based on a high-resolution method to extract the signals produced by the Mt. St. Helens source from spurious waves or noise in each record. This facilitates interpretation of the wave trains in terms of propagation modes. It is thus shown that the Lamb mode L_0 is present in the low-frequency part of all the signals, whereas acoustic modes (more probably A'_2) are needed to explain all the properties of the high-frequency part, which is clearly observed for a westward and a southward propagation.

R.W. Whitaker, J.P. Mutschlecner, M.B. Davidson and S.D. Noel, **"Infrasonic Observations of Large-Scale HE Events,"** in Proceedings of the Fourth International Symposium on Long-Range Sound Propagation, NASA Langley Research Center, May 16-17, 1990, NASA Conference Publication 3101, (1990).

Abstract: The Los Alamos Infrasound Program has been operating since about mid-1982, making routine measurements of low frequency atmospheric acoustic propagation. Generally, we work between 0.1 Hz to 10 Hz; however, much of our work is concerned with the narrower range of 0.5 Hz to 5.0 Hz. Two permanent stations, St. George, UT, and Los Alamos, NM, have been operational since 1983, collecting data 24 hours a day. For the purposes of this discussion, we will concentrate on our measurements of large, high explosive (HE) events at ranges of 250 km to 5330 km. Because our equipment is well suited for mobile deployments, we can easily establish temporary observing sites for special events. The measurements in this report are from our permanent sites, as well as from various temporary sites. In this short report we will not give detailed data from all sites for all events; rather, we will present a few observations that are typical of the full data set.

The Defense Nuclear Agency sponsors these large explosive tests as part of their program to study airblast effects. A wide variety of experiments are fielded near the explosive by numerous Department of Defense (DOD) services and agencies. Our measurement program is independent of this work; we use these tests as energetic known sources, which can be measured at large distances. Ammonium nitrate and fuel oil (ANFO) is the specific explosive used by DNA in these tests. The table, immediately below gives the test names, dates, charge weights, and number of infrasonic stations operated for each test. All tests were fired at White Sands Missile Range, NM.

Event	Date	Weight (Tons)	Sites
Millrace	9/16/81	600	1
Pre Direct Course	10/7/82	24	2
Direct Course	10/26/83	600	4
Minor Scale	6/27/85	4800	4
Misty Picture	5/14/87	4800	5
Misers Gold	6/01/89	2400	8

A. Gudesen, "**Application of the SAFARI model to sound propagation in the atmosphere,**" J. Acoust. Soc. Am. 87, 1968 (1990). [May]

Abstract: The SAFARI (seismo acoustic fast-field algorithm for range-independent environments) wave propagation model is applied for the first time to low-frequency atmospheric sound propagation and tested by means of synthetic and real-world data. Problems experienced with the use of SAFARI are discussed in detail. Good agreement of the model output with theoretical predictions is achieved for two half spaces (air/ground). Available meteorological data up to 5000-m height are applied to the model in the next step in order to compute sound transmission loss versus range and recover height. Results are given in transmission loss contour plots covering a field of 1000 m height and 30,000 m in range. The influence of typical sound velocity profiles including strong gradients close to the ground is investigated. It turns out that knowledge of meteorological data is most relevant for heights up to about 200 m for sound propagation modeling within a field of interest as above. SAFARI is finally compared with a fast-field program developed at the US. Army Construction Engineering Laboratory. This test yields very good agreement between both model predictions on a test case in which a real-world sound profile is used. It has to be emphasized that all results are for very low frequencies where finite impedance ground effects are minimal. One would expect to see differences at higher frequencies. These encouraging results give rise to recommending the use of the models in a number of interesting applications such as various types of acoustic detection system and civil noise control.

J.P. Mutschlecner and R.W. Whitaker, **"Correction of infrasound signals for upper atmosphere winds,"** Los Alamos National Laboratory Technical Report No: LA-UR-90-1997 (CONF-9005236-2), (1990). NTIS Number: DE90013177/HDM.

Abstract: Infrasound waves propagate in the atmosphere by a well known mechanism produced by refraction of the waves, return to earth, and reflection at the surface into the atmosphere for subsequent bounces. In this instance three rays are returned to earth from a region centered at about 50 kilometers in altitude and two from a region near 110 kilometers in altitude. The control of the wave refraction is largely dominated by the temperature-height profile and inversions; however, a major influence is also produced by the atmospheric wind profile. It obviously can be expected that infrasonic signal amplitudes will be greatly influenced by the winds in the atmosphere. The seasonal variation of the high altitude atmospheric winds is well documented. The very strong seasonal variation has the ability to exert a major seasonal influence on infrasonic signals. It is our purpose to obtain a method for the correction of this effect.

S.D. Noel and R.W. Whitaker, **"Comparison of Noise Reduction Systems,"** Los Alamos National Laboratory Technical Report: LA-12008-MS, June, (1991). [June]

Abstract: When using infrasound as a tool for verification, the most important measurement to determine yield has been the peak-to-peak pressure amplitude of the signal. Therefore, there is a need to operate at the most favorable signal-to-noise ratio (SNR) possible. Winds near the ground can degrade the SNR, thereby making accurate signal amplitude measurement difficult. Wind-noise reduction techniques have been developed to help alleviate this problem; however, a noise-reducing system should reduce the noise, and should not introduce distortion of coherent signals. This paper describes an experiment to study system response for a variety of noise-reducing configurations to a signal generated by an underground test (UGT) at the Nevada Test Site (NTS). In addition to the signal, background noise reduction is examined through measurements of variance. Sensors using two particular geometries of noise-reducing equipment, the "spider" and the "cross" appear to deliver the best SNR. Because the "spider" configuration is easier to deploy, it is now the most commonly used.

A.D. Pierce, **"Wave equation for sound in fluids with unsteady inhomogeneous flow,"** J. Acoust. Soc. Am. 87, 2292 (1990). [June]

Abstract: An approximate wave equation is derived for sound propagation in an inhomogeneous fluid with ambient properties and flow that vary both with position and time. The derivation assumes that the characteristic length scale and characteristic time scale for the ambient medium are larger than the corresponding scales for the acoustic disturbance. For such a circumstance, it is argued that the accumulative effects of inhomogenieties and the ambient unsteadiness are satisfactorily taken into account by a wave equation that is correct to first order in the derivatives of the ambient quantities. A derivation that consistently neglects second- and higher-order terms leads to a concise wave equation similar to the familiar ordinary wave equation of acoustics. The wide applicability of this equation is established by showing that it reduces to previously known wave equations for special cases and by showing, with the eikonal approximation, that it yields the geometrical acoustics equations for ray propagation in moving inhomogeneous media.
C.H. Hagelstein and H.G. Nygren, **"Infrasonic Technique for Air Surveillance,"** Foersvarets Forskningsanstalt, Stockholm (Sweden) Technical Report No: FOA-C-20898-2.2, August (1992). NTIS Number: PB93-117851/HDM.

Abstract: This report describes a simple principle for detecting infrasonic sound waves using an equipment constructed for that purpose. Registrations from different kinds of infrasonic sound sources are presented and discussed. The equipment is applicable in the lower part of the infrasonic frequency range and cannot be used for detecting helicopter sound.

R.W. Whitaker and S.D. Noel, **"Integrated Verification Experiment data collected as part of the Los Alamos National Laboratory's Source Region Program. Appendix C, Infrasonic measurements of IVE events: Los Alamos Source Region Program,"** Los Alamos Laboratory Technical Report no: LA-UR-92-4409, December (1992). NTIS Number DE93015856/XAB.

Abstract: The summary report by Tom Weaver gives the overall background for the series of IVE (Integrated Verification Experiment) experiments including information on the full set of measurements made. This appendix presents details of the infrasound data for the and discusses certain aspects of a few special experiments. Prior to FY90, the emphasis of the Infrasound Program was on underground nuclear test (UGT) detection and yield estimation. During this time the Infrasound Program was a separate program at Los Alamos, and it was suggested to DOE/OAC that a regional infrasound network be established around NTS. The IVE experiments took place in a time frame that allowed simultaneous testing of possible network sites and examination of propagation in different directions. Whenever possible, infrasound stations were combined with seismic stations so that a large number could be efficiently fielded. The regional infrasound network was not pursued by DOE, as world events began to change the direction of verification toward non-proliferation. Starting in FY90 the infrasound activity became part of the Source Region Program which has a goal of understanding how energy is transported from the UGT to a variety of measurement locations. [Descriptors: nuclear explosions; underground explosions; acoustic measurements; energy transfer; experimental data; LANL; nuclear explosion detection; seismic detection; verification.

E.M. Jones, F.N. App and R.W. Whitaker, **"Ground motions and the infrasound signal: A new model and the discovery of a significant rebound signal. Los Alamos Source Region Program,"** Los Alamos National Laboratory Technical Report No: LA-UR-93-861, March (1993). NTIS Number DE93015858/XAB.

Abstract: A model is presented that relates infrasound signals from underground nuclear tests to the peak vertical velocity at surface-ground-zero. For the most part, agreement between the model and observations is good, the exceptions being events conducted in shallow tuff layers in Yucca Flat. These events all have low values of the peak surface velocity. The authors have determined that the lack of agreement for these events is due to an unusual, second spall event. A stress-wave calculation is presented that reproduces the second-spall phenomenon and indicates that it is due to interference of cavity-rebound-associated signal with the initial ballistic motion of the surface layers. The effect of the rebound signal is to increase the amplitude of the infrasound signal and thus make low velocity events more detectable. [Descriptors: nuclear explosion detection; underground explosions; acceleration; acoustic detection; amplitudes; cavities; comparative evaluations; data analysis; fragmentation; ground motion; Hz range; mathematical models; Nevada Test Site; nuclear explosions; sound waves; Tuff; wave propagation.]

S.N. Kulichkov, "**Long-Range Propagation of Sound in the Atmosphere, A Review,**" Izv. Atm. and Ocean Phys. 28, 253 (1994).

Abstract: The results of investigations of long-range propagation of sound from natural and artificial sources in the atmosphere (auroras, microbaroms, sonic booms, thunderstorms, volcanic eruptions, explosions, etc.) are discussed. Special attention is devoted to infrasonic waves from Earth-surface sources of different energy. Questions concerning the temporal stability of the acoustic properties of atmospheric waveguides are discussed briefly. The applicability of investigations of long-range sound propagation in problems of sounding the atmosphere is discussed.

M. Davidson and R.W. Whitaker, "**Miser's Gold,**" Los Alamos National Laboratory Technical Report: LA-12074-MS, February (1992). [February]

Abstract: A 2440-ton high explosive (HE) test named Miser's Gold was performed at White Sands Missile Range, New Mexico, on June 1, 1989, at 15:30 UT. Such experiments provide airblast data for weapons effects studies sponsored by the Department of Defense.

The acoustic signals produced by the event were monitored at ten locations, with ranges of 250 km to 1372 km with sensors operating in the infrasound range. The measured data are presented and analyzed to verify and to quantify the infrasonic signal from the HE source and to study the long-range propagation of low-frequency acoustic waves.

R.W. Whitaker, S.D. Noel, J.P. Mutschlecner and M. Davidson, "**Infrasonic Monitoring of UGTs and Earthquakes for Discrimination,**" presented at the DOE/LLNL Verification Symposium on Technologies for Monitoring Nuclear Tests Related to Weapons Proliferation, Las Vegas, NV, May 6-7 (1992).

Abstract: None.

R.W. Whitaker and J.P. Mutschlecner, "**Pressure Distribution in the First Bounce,**" in Proceedings of the Fifth International Symposium on Long Range Sound Propagation, The Open University, England, Edited By K. Attenborough, K.M. Li and H.E. Bass, May 24th-26th, page 415 (1992).

Abstract: No paper published in the Proceedings. Only the abstract.

Infrasonic observations will be presented of the pressure field generated by the ground motion from an underground explosion and measured at ranges of 110 km to 300 km. The measurements were made by an array of 4 microphones at a range of 220 km from the source and stations of single microphones spaced about 10 and 20 km east and west of the array. The first single station was a range of 110 km, in the middle of the classical zone of silence. This experimental plan allowed the distribution of pressure as function of range in the first bounce to be determined. Rocketsonde data for upper atmospheric winds were available for the event day and were used for ray tracing studies. These results will be compared to the observations.

A.J. Bedard, **"Low-Frequency sound waves associated with avalanches, atmospheric turbulence, severe weather, and earthquakes,"** J. Acoust. Soc. Am. 94(3), 1872 (A), (1993). [September]

Abstract: Recent measurements of naturally occurring atmospheric sound waves near 1 Hz indicate potential uses for monitoring and studying a variety of geophysical processes including avalanches, atmospheric turbulence, severe weather and earthquakes. A review presents typical signal characteristics including spectral content, showing clear differences between signals from various sources. Possible generation mechanisms are discussed in the context of these data and possible potential practical uses indicated.

H. Kanamori, J. Mori and D.G. Harkrider, **"Excitation of atmospheric oscillations by volcanic eruptions,'** J. Geophys. Res. 99, 21,947 (1994). [November]

Abstract: We investigated the mechanism of atmospheric oscillations with periods of about 300 s which were observed for the 1991 Pinatubo and the 1982 El Chichon eruptions. Two distinct spectral peaks, at T=270 and 230 s for the Pinatubo eruption and at T=195 and 266 s for the El Chicon eruptions, have been reported. We found similar oscillations for the 1980 Mount St. Helens and the 1883 Krakatoa eruptions. To explain these observations, we investigated excitation problems for two types of idealized sources, "mass injection" and "energy injection" sources, placed in an isothermal atmosphere. In general, two modes of oscillations, "acoustic" and "gravity" modes, can be excited. For realistic atmospheric parameters, the acoustic and gravity modes have a period of 275 and 304 s, respectively. For a realistic time history of eruption, atmospheric oscillations with an amplitude of 50 to 100 Pa (0.5 to mbar) can be excited by an energy injection source with a total energy of 10^{17} J. This result is consistent with observations and provides a physical basis for interpretation of atmospheric oscillations excited by volcanic eruptions.

W.L. Nicholson, **"Detection Probabilities for Early Acoustic Monitoring,"** Pacific Northwest Laboratory Technical Report: PNL-10399, March (1995).

Abstract: Olsen and Nicholson analyzed data from USAEDS/acoustic monitoring of the atmosphere nuclear testing as part of the technical evaluation following Alert 747. Modeling of detection probability as a function of distance and yield (Figure 1, page 11) produced the following USAEDS/acoustic capability statements:

(1) Large atmospheric events, say greater than 500 KT were always detected since even at 10,000 kilometers detection probability is about 80% for an individual station.

(2) For good sensitivity to small atmospheric events, say 3 KT, several stations were needed not more distant than 2000 kilometers.

(3) A network with no station closer than 2000 kilometers would probably fail to detect an atmospheric event of less than 1 KT yield.

USAEDS/acoustic monitoring experience may not relate directly to current questions concerning the need for acoustic monitoring to a CTBT monitoring system. However, two uses for such experience appear to be:

1. as a direct benchmark for computer simulation of sound propagation in the atmosphere; and,

2. with the triple caveat of knowledge of relative strength of source terms (underground versus atmospheric), knowledge of relative capabilities of measurement technologies (state-of-art versus USAEDS/acoustic) and yield scaling to levels of CTBT concern, as a ball park capability statement for any proposed acoustic monitoring system.

D.O. Revelle, **"Historical Detection of Atmospheric Impacts by Large Bolides Using Acoustic-Gravity Waves,"** Los Alamos Laboratory Technical Report LA-UR-95-1263, April (1995). [Paper presented at the International Conference on Near-Earth Objects Sandia National Laboratory; Explorers Club and the United Nations, April 24-26, 1995 in New York City.] [April]

Abstract: During the period from about 1960 to the early 1980's a number of large bolides (meteor fireballs) entered the atmosphere which were sufficiently large to generate blast waves during their drag interaction with the air. For example, the remnant of the blast wave from a single kiloton class event was subsequently detected by up to six ground arrays of microbarographs which were operated by the U.S. Air Force during this pre-satellite period. Data have also be obtained from other sources during this period as well and are also discussed in this summary of the historical data. The Air Force data have been analyzed in terms of their observable properties in order to infer the influx rate of NEO's (near-Earth objects) in the energy range from 0.2 to 1100 kt. The determined influx is in reasonable agreement with that determined by other methods currently available such as Rabinowitz (1992), Ceplecha, (1992; 1994b) and by Chapman and Morrison (1994) despite the fact due to sampling deficiencies only a portion of the "true" flux of large bodies has been obtained by this method, i.e., only sources at relatively low elevations have been detected. Thus the weak, fragile cometary bodies which do not penetrate the atmosphere as deeply are less likely to have been sampled by this type of detection system. Future work using the proposed C.T.B.T. (Comprehensive Test Ban Treaty) global scale infrasonic network will be likely to improve upon this early estimate of the global influx of NEO's considerably.

D.O. Revelle, **"Infrasonic Observations of Meteors,"** Paper presented at ARPA sponsored 1995 Monitoring Technologies Conference, Chantilly, VA, May 15-18, (1995). [May]

Abstract: Hypersonic entry of large meteoroids (bolides) deep into the atmosphere can generate low frequency acoustic-gravity waves whose properties can be interpreted using various approaches to give pertinent details about their source. During the period from 1960-1974, the U.S. Air Force operated a global infrasonic network whose primary purpose was to monitor distant nuclear explosions in the atmosphere. During this period the Air Force network also detected at least 10 large bolide events, with deduced source kinetic energies ranging from 0.2 kt to 1.1 MT (TNT equivalent) at ranges from a few hundred to several thousands of miles from the sources. One particular 14 kt bolide event was detected by 6 arrays at ranges from 2300 to 8500 miles away. At least three of the events also struck the earth and were also detected by seismic techniques as well. Thus, not only were accurate source locations available by two of the primary technologies proposed for the CTBT, but independently calibrated yield estimates were also possible in some cases. In addition, these data allow the determination of the global influx rate of these large, deep penetrating "airwave" objects. Possible synergy with future efforts in this area seems highly desirable since at the smaller energies of interest to the CTBT, these bolide signals should occur quite frequently on a global scale (for a source energy of 1 kt for example, we estimate that $8\pm$ events could, on the average, be expected to occur globally within one

year). Detection of these bolide signals should be readily achievable given the system bandpass and array separations currently proposed for the CTBT in Geneva.

L. Liszka and K. Waldemark, **"High Resolution Observations of Infrasound Generated by the Supersonic Flights of Concorde,"** Institute for Rymdfysik, Swedish Institute of Space Physics, IRF Scientific Report 224, May (1995). [May]

Abstract: None. The paper discusses some of the fine structure of acoustic signals radiated from Concorde flights.

D.O. Revelle, **"The Fall of the Revelstoke Meteorite: March 31, 1965: Seismic & Infrasonic Analyses of the Impact Location of the Meteorites and Search for Cratering Features,"** Los Alamos Laboratory Technical Report LA-UR-95-1952, June 1, (1995). [June]

Abstract: None.

R.R. Blandford and D.A. Clauter, **"Capability Estimation of Infrasound Networks,"** AFTAC-Technical Report [Unpublished] July (1995).

Abstract: Amplitude-distance and amplitude-yield relations for infrasonic signals from atmospheric nuclear explosions, together with observed infrasound system noise values, are determined by a review of the literature and of historical observations. The resulting parameters are used to determine the detection performance of the infrasound networks proposed by the Infrasound Experts of the Conference on Disarmament.

The Expert's 60-station network has a 2-station, 90% detection threshold of 0.4-0.7 kilotons (kt) worldwide, and the 70-station network has a threshold of 0.4-0.6 kt. These results are consistent with probabilistic evaluation of the performance of smaller past networks by Nicholson (1995).

If, in response to superior cultural and radionuclide detection in the Northern Hemisphere, the infrasound network was required only for the Southern Hemisphere oceans, then only 23 stations are required to maintain the Southern Hemisphere 90% threshold below 1 kt. Capital costs for such a network are estimated at $4.7M as compared to the Experts cost estimate of $10.8M for the 60-station, 4-element array network.

The cost of a 16-element array is estimated to be $0.24M, as compared to $0.18M for a 4-element array. If such arrays were installed in the Southern Hemisphere, fewer than 12 stations would be required to maintain better than a 1-kt threshold in the region of interest at a total capital cost of less that $2.9M.

In general, for any network considered, 2-station thresholds are decreased by a factor of 2 in yield if the 50% threshold is specified instead of the 90% threshold.

Recent results in pipe-array engineering and design suggest that the performance achieved in the past, which is the basis for these calculations, might be substantially improved in the future such that even a 4-element array could achieve the results given above for 16-element arrays.

D. R. Christie, **"Design of a Global Infrasound Monitoring Network,"** Letter and attachment to Dr. Peter Marshall, August 9, (1995).

Abstract: None.

D.J. Simons, **"Atmospheric methods for nuclear test monitoring,"** Conference Title: NATO (ASI)/monitoring a comprehensive test ban treaty Conference Location: Algrave (Portugal) Conference Date: 23 Jan - 2 Feb 1995; Los Alamos National Laboratory Technical Report No: LA-UR-94-3940; CONF-950151-3, (1995). NTIS Number DE95003659/XAB.

Abstract: Abstract: The U.S. DOE sponsored research investigating atmospheric infrasound as a means of detecting both atmospheric and underground nuclear tests. Various detection schemes were examined and were found to be effective for different situations. It has been discovered that an enhanced sensitivity is realizable for the very lowest frequency disturbances by detecting the infrasound at the top of the atmosphere using ratio sound techniques. These techniques are compared to more traditional measurement schemes. [Descriptors: atmospheric explosions, nuclear explosion detection; sudden ionospheric disturbance; acoustic measurements; underground explosions-nuclear explosion detection.]

D.B. Clarke, J.W. White and D.B. Harris, **"Hydroacoustic Coupling Calculations for Underwater and Near-Surface Explosions,"** University of California Technical Report: UCRL-ID-122098, September 8 (1995). [September]

Abstract: Nuclear explosions conducted at sea may be detonated underwater or above the ocean surface. A significant fraction of the energy from an underwater explosion will couple to the SOFAR channel (the efficient ocean acoustic waveguide) as acoustic waves, and through the ocean to the solid earth as seismic waves. Previous work indicates that explosion energy can be significantly decoupled from the ocean by detonating the explosive device above the ocean surface. Here we report that the effect is greater than prior estimates.

The degree of decoupling has been estimated with a sequence of linked computer calculations. A strong-shock calculation using LLNL's hydrodynamics code CALE, was followed by a weak-shock propagation calculation with NRL's NPE code. We estimate the coupling factor by calculating the energy of the shock waves at a range of 10 kilometers from the source for a variety of source positions above and below the ocean surface. The coupling factor for a given shot configuration is the ratio of the corresponding shock wave energy to the energy of the shock from a reference underwater event, fully-coupled at 1 kilometer depth.

In previous work, we performed a radiation transport calculation with a weapons-effects code which verified that our model of the nuclear device--a ball of iron gas--was sufficiently accurate for this simulation. In this report we document the CALE - NPE linkage in some detail. This part of the calculation is critical to providing a starting field for linear acoustic models that will estimate the early-time signature of long-range observations of nuclear detonations.

Even before the long-range acoustic calculations are carried out, it is possible to estimate that 1 kiloton bursts should be detectable with a hydrophone system at basin distances. Explosions of 1 kiloton yield detonated 1 kilometer above the ocean surface, couple as much energy as a 10 kilogram explosion at the axis of the SOFAR channel. Such events should be detectable with hydrophone systems at ranges of several thousand kilometers.

D.I. Havelock, X. Di, G.A. Daigle and M.R. Stinson, **"Spatial coherence of a sound field in a refractive shadow: Comparison of simulation and experiment,"** J. Acoust. Soc. Am. 98, 2289 (1995). [October]

Abstract: The coherence of a sound field in a refractive shadow near the ground has been examined for microphone separations which are transverse or longitudinal to the direction of propagation. Single tone test signals at 1 kHz, 500, and 100 Hz were measured at a range of 700 m by a microphone array, spanning 270 m longitudinally and 15 m transversely. Estimates of the spatial correlation, based on 10-minute averages, indicate transverse coherence lengths less than 2 m and longitudinal correlation lengths less than 7 m for moderately strong upward refraction conditions. Numerical simulations were done which emulate the experimental conditions. The Green's-function method for the parabolic equation was used to generate two-dimensional sound fields within a refractive shadow. An upward refracting atmospheric model with homogeneous isotropic Gaussian turbulence was used. The coherence in the simulated sound fields compares well, qualitatively, with the experimentally measured coherence. Both simulation and experiment indicate that the longitudinal coherence length within a refractive shadow is dramatically less than is typically observed outside of a shadow. The reduced coherence will restrict the useful aperture size of beamforming arrays deployed in acoustical non-line-of-sight conditions.

C.R. Wilson, J.V. Olson and D.B. Spell, **"Natural Infrasonic Waves in the Atmosphere: their characteristics, morphology and detection,"** University of Alaska Technical Report ARS-95-039, October 16, 1995. [October]

Abstract: None. The report discusses signal analysis, noise suppression and detection for infrasonic arrays and five source classes of natural background infrasound: auroral infrasonic waves, microbaroms, volcanic infrasound, earthquake infrasound and aerodynamic infrasound (MAW).

D.A. Clauter and R.R. Blandford, **"Capability Modeling of the Proposed International Monitoring System 60-Station Infrasonic Network,"** paper to be presented at the Fall meeting of the American Geophysical Union, San Francisco, CA, December 15-19, (1996). [December]

Abstract: None. Paper deals with the detection and location capability of a proposed 60 - station international infrasonic network.

APPENDIX A

This appendix reproduces the **"Bibliography of Infrasonic Waves,"** J.E. Thomas, A.D. Pierce, E.A. Flinn and L.B. Craine, Geophys. J.R. astr. Soc. 26, 399 (1971).

The bibliography is one of several papers on infrasonic waves which appeared in the 1971 Volume 26 special issue on infrasonics and atmospheric acoustics published by The Geophysical Journal of the Royal Astronomical Society.

The bibliography organizes the listed papers into five categories:

I. Papers related to the design and description of instrumentation and to the analysis of data.

II. Papers in which the primary topic is the source mechanism for the generation of acoustic, infrasonic, acoustic-gravity, and gravity waves.

III. Papers related to the measurement, observation, and theory of ionospheric waves.

IV. Ground-level observations of pressure waves.

V. Theoretical papers on atmospheric pressure waves.

Instrumentation and data analysis

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APPENDIX B

This appendix reproduces a bibliography of papers published in the text:

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